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Programming For The Natives: What is it? What's In It For The Kids?

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Abstract

Programming is many things to many people, and not everyone agrees on its potential for human learning. This is especially true at a time when ever younger children are increasingly "expert" gamers, tweeters, information-seekers, and digital bricoleurs. Often self-taught, or at least grabbing much of what they know outside the classroom, today's youngsters (also referred to as digital natives) indeed surprise, and on occasion surpass us, with their clever uses of all things digital. Question is: how much of this "expertise" is doomed sufficient by experts in the field? This paper looks at programming as an opportunity to address issues of agency, control, and interaction styles, as played out in the creative and critical uses of "smart" tools by curious minds. The focus is on views and uses of "programming" as a means for; 1) making things do things *(instruct them to follow and execute orders); 2) "*animating" things (*endow them with a mind of its own, teach them to "look out for themselves"*); *and 3)* poking things *(modulate how things act or interact by tweaking some parameters in their environment). I present settings where youngsters are asked to give and execute orders, take over control and let go of it. I draw lessons for the design and evaluation of programmable play kits for young children.*

Keywords

Program, model, object-relation, agency, control, animate, appropriation, smart" tools, children

Introduction

At a time when computational devices have become an integral part of our lives, and make it easier to run programs, model interactions, and simulate behaviours, people's ideas of what programming, modelling, or "simuling" are about are deeply changing, as are their ways of relating to existing authoring and editing tools. More than in the past, performance and simulation are granted a new place besides language, and there is no doubt in most people's minds that downplaying the role of *new media literacy* (literacies *beyond print*) would be today's equivalent of promoting illiteracy. What is less clear, to this day, is the status of programming itself (beyond modelling and simulating), and its alleged benefits in helping youngsters acquire the competences they need to become fluent ITC users. In other words, how deep under the hood should we be looking, and why, in order to satisfy 21st century skills requirements? What's there to be gained in the first place? And what's in it for the children?

Programming is many things to many people, and not everyone agrees on its potential for learning. Understanding today's children's ways of navigating and blending physical, virtual, and digital, and using ICT provides a unique window into gauging the pros-and-cons of programming in the 21st century. It does so by challenging our own assumptions on what it means to be smart, literate, or creative, athus allowing us appreciate the natives' strengths before we advise on what they'll be missing, if left on their own (Ackermann, 2011).

The purpose of this paper is to discuss the intricacies between modelling, simuling, and programming from an experiential perspective. Building on research with, and observations of, children, we explore issues of agency, control, and interaction styles, or relational preferences, as played out in the creative and critical uses of "smart" tools: in this case, any artefact or device, physical or virtual, that is either seen as being responsive and inner-driven, treated as if it were, or made to do things on its own. The focus is on how children, and adult-experts, use and think of "programming" as a means for exploring and optimizing the interplay between a human (usually themselves) and unequally responsive, surprising, or reliable devices.

I discuss why exploring the "logic" of gives and takes, through interacting with, relying on, or controlling "smart" toys, or endowing stuff with smarts, can enrich our experience and understanding of "programming" (in the broad sense of "making things do things). I present settings in which youngsters are invited to use objects as models, give and execute orders, take over control and let go of it, animate things, and simulate behaviours. I draw lessons for the design and evaluation of "programmable" play [-learning] kits for young children.

New media ecologies, new genres of engagement: the changing relations between today's youngsters and their artefacts

Animated toys have always occupied a special place in people's lives. They are intriguing because they do things. Sometimes they even seem to have a mind of their own. Many are responsive to our solicitations. In all cases, objects that behave are treated differently than inert toys. Clearly, toys need not be animated to *be" made to behave"* in a child's imagination. In their pretense play, children endow things with life all the time. Puppets, dolls, stuffed animals, and even sticks and brooms are made into living beings, and endowed with all kinds of special powers. Yet, toys that *actually* behave elicit new ways of relating, and are used in different ways (Turkle, 1984, Ackermann, 2000)

Things that do things, and "telepathic" toys

T*hings that do things* are "objects-to-think-with", in Papert's sense, yet of a particular kind (Papert, 1980). They intrigue us because of 1) their hybrid nature (look like things yet act like people); 2) their relative autonomy (responsive but with a mind of their own); and 3) their singular form of "smarts". It is their believable artificiality and "forgiving" nature that make it possible to explore, enact, and work through issues of identity formation and object-relations, and to learn about how different creatures [people, animals, plants] or things [stones, tools, machines] act in the world, communicate amongst themselves, and respond to a child's solicitations.

What I call *"telepathic" toys* have this additional property that they respond to our solicitations at a distance, or at a later time. So, for example, if I push a button on my controls, a cartoon sets itself in motion on a TV screen, at the other end of the room; and as I zap between channels, I can feel the thrills of making things appear and respond remotely. No surprise if even very young children fall in love with light switches and remote controls! A similar thrill can be felt as we engage in face-to-face communication with close friends, away from home, via skype.

Distance action, remote control, and tele-presence, I suggest, are at the core of what programming is about, at least experientially, because it is no longer just a matter of making things do things by pushing them around physically. Instead, it is about signaling what it is we want them to do. It is about "telling them", giving them orders, or instructions, mediated-ly. As parents say to their 2 years olds: Use words! Don't just punch (or use brute force)!

Things that stand for something else, and things that stand on their own!

In a rich corpus of experiments, Judy De Loache and colleagues have shown that young children have difficulties in understanding the representational nature of objects that are interesting in themselves (De Loache, Uttal & Pierroutsakos, 1998). A scale model of a room, for example, is salient and appealing in its own right, and treated as such by a 3-year-old. In the well-known teddy bear experiment, a scale model of a room gives children information about a full-sized room that the model is meant to represent. In a preliminary phase, DeLoache makes it clear to the children that the scale model is an exact mini-replica of the full-sized room, and that whatever happens in the model simultaneously happens in the room: "A big bear lives in the big room and a little bear in the little room. Whatever the baby-bear does, the daddy-bear does too". De Loache then hides the baby bear in various places in the scale model and asks the child to find the big bear "who is hiding at the exact same place in the big room". Understanding that the miniature replica stands for the larger room, the authors argue, requires that the child disentangle two functions embedded in the scale model: while it is an object in itself, it also serves as a representation of something else. Such dual representation is not constructed before age four..

Variations on the teddy-bear experiment further suggest that the task is, ironically, made easier if the "model" is a picture (2D) or, even better, when the symbolic relation between model and room is altogether removed. This was done in the ingenious "shrinking room" experiment, where 2-3-year olds are told that the scale model *actually IS the room —which has been shrunk by the incredible shrinking-machine*. The enactment of the shrinking operation, as unbelievable as may be, is well understood by the children, and "forces" the model-room equivalence, thus allowing for successful retrieval. According to De Loache, reserachers generally agree that arbitrary symbol systems, such as numbers and letters, are difficult for young children because they bear no resemblance to their referents. What is less obvious, is that the more engaging a "representation" is for its own sake, the harder it is to treat it as something which stands for something else. And indeed one wonders, why wouldn't children take a 3D model just for what it is: a little theatre, a doll-house of sorts, a mini-stage where they can enact and play out different scenes afforded by the décor, props, and mini-figures (like teddy-bears)?

Models, simulations, microworlds

In discussing the implications of their findings for education, De Loache and colleagues express doubts as to what children may take away from watching edutainment programs, such as "Sesame Street," in which letters and numbers are being personified, and in which they talk, sing, and participate in beauty pageants. In their view, turning abstract symbols into concrete objects is likely to make their meaning less, rather than more, clear to young children (De Loache, Uttal & Pierroutsakos, 1998). Does this imply, as the authors suggest, that symbol systems, or models, ought to be more abstract, less lively, to engage learners in symbolic activities? I am not sure. Children's resistance to treating interesting objects as *representational* may be call to challenge *correspondence theories* of representation altogether (Lakofff & Johnson, 1981), by recognizing that external representations, or models, are never copies of reality but translations. And like any translation, they transform the original. If such is the case, why not let kids be the naïve *correspondence theorists* they are, and encourage (rather than dissuade) them to treat a model (static or dynamic) not as a *simulator* but as a *stimulator* (Resnick, 1990), or a *microworld* (Papert, 1980). The difference between the two lays in their truthfulness to reality. While simulations are generally meant to be true to real, microworlds, as Papert defines them, claim their status as alternative "realities". Their purpose is not to mimic, but to bring into being and open up for scrutiny otherwise invisible mechanisms or unthinkable thoughts.

In sum, rather than debating whether representations should be more or less abstract, a more radical view is to move away from correspondence theories altogether, and to provide learners with a rich and varied palette of tools, techniques, and manipulatives, to help them capture, visualize, enact, and revisit otherwise “hidden” aspects of some intriguing phenomenon.

Machines and mechanisms – Agency, causation, delegation

Early on, children endow objects that behave with a life of their own, and treat them *as if* they were animated. This not to say that 5-year-olds believe that a computer or a robot is alive: They know it is not (Carey, 1985, Turkle, 1984). Yet in their play, the children still treat them as social agents capable of initiating, sustaining, and controlling behaviours. Research on children’s animism by Inagaki & Hatano (1987), Carey (1985) and Steward (1982) further suggests that children’s tendency to attribute agency applies beyond ‘intelligent’ artefacts to include transactions among objects in general.

The most striking characteristic of children’s understanding of causal transactions is that they describe the moves between interacting entities (alive or not, agent or recipient) in terms of how each impacts, or is impacted, by another’s behaviour, either through direct or mediated action. Note that in the case of direct action, an agent A does something to a recipient B, by *impacting it physically*, whereas in the case of mediated action, agent A signals something to B, and B acts or signals back accordingly. In both cases, agents at play tend to be animated, at least while currently active, and recipients tend to be objectified. In a chain of transactions, any particular object is by turns seen as an agent or a recipient, depending on whether it is perceived as generating an action from within (agent), or responding (recipient). (Ackermann , 1991).

A study by Ackermann and Brandes (Brandes, 1992) on children’s conceptions of simple machines brings further evidence to the notion that the criteria used to determine 'machineness' are relative to a tool’s ability to give back something different than what was put in the first place. In exploring elementary-school children’s sense of mechanism, we asked small groups of 5 to 9 year-olds *what*, in their eyes, *makes something a machine*, and *how machines work*. We then presented individual children with small collections of images showing instances of devices with similar functionality, yet different in their source of power, level of complexity, and control mechanisms. We asked the children which of the objects were machines, and why. Examples of collections include: skateboard, bicycle, car (all used for transportation); and scissors, power lawn mower, push lawn mower (all used for cutting). Items were spresented one by one.

Although children were far from unanimous as to which objects were machines, a number of regularities emerged. In session one, all groups produced *definitions by use* (A machine is something that helps you go places). Groups’ ideas on how machines work revolved around four arguments: they have motors, powers, electricity, or a mechanism. In session two, individual children’s groupings showed that almost everyone drew a line between machines and non-machines in terms of an object’s ability to transform an input in significant ways. An object, then, is a machine if it modifies what you do to it in ways that make a difference. Thus for one child *Scissors* are not a machine because “it’s you who cut”. A *push lawn mower* is a machine because “*you* push and *it* cuts”. To the question: “what are scissors then? The child answers “a tool”. For another child a *car* is a machine because “it has a motor”. A *bike* is not a machine because “its you who pedal”. Yet a bicycle-powered *aircraft* (as seen at Boston Science Museum) is a machine because “if you pedal and it flies...then it’s got to be a machine”! In all cases, the value added requires an entity capable of generating it from within. Yet the entity itself is often treated as a black box. Only upon request do children refer to it as the 'brain', the 'motor', or the 'powers'.

What does this all have to do with programming?

Media theorist and critic Douglas Rushkoff has a saying: Program or be programmed! In his view, if we don't partake in creating a culture that at least knows there's a thing called programming, then we'll end up being not the programmers, but the users, and, worse, the used. To which he adds: "Whether or not today's "creatives" (artists, designers, makers) are interested in studying the impact of technology *per se,* the learning and sharing of techniques that most people accept passively is a statement of emancipation from unidirectional tech consumption (Rushkoff, 2010). This view is not so different from Papert's own statement that computers shouldn't be used to "program "the child, but that *the child should program the computer* and, in doing [I quote]: "acquire a sense of mastery over a piece of the most powerful technology and, at the same time, establishes an intimate contact with some of the deep ideas from science, maths, and the art of intellectual model-building" (Papert, 1980).

Problem is: Like computation itself, programming is a Pygmalion. It becomes what you want it to be. To a scientist, for example, it may be a powerful tool for modeling or "simuling" the dynamic pattern of interactions at play in a complex ecosystem. To a game-designer, it may be a means to create a 3D interactive virtual habitat or an animation. And to a developmental psychologist, of which I am, the most intriguing and somewhat under-explored promises of programming lay in its ability to bring to the fore issues of control and communication between humans and machine (Ackermann, 1991).

Programming has also changed, both its look-and-feel and nuts-and bolts, with the developments in computing (object-oriented programming, parallel distributed computing, A-life) as well as the uses of informal 'programming' (ambient computing, paper computing), and its growing popularity among non-computer-scientists. New materials, display and projection capabilities are at people's avail allowing many adults—and youngsters— these days to "program," one way or another, which makes one wonder: What is programming in the first place? Is it about writing code? Is it a way of thinking? Anything in-between? The answer to this question is not simple.

Programming games – Learning from the children!

Programming, at its core, is about giving instructions—or commands—to be executed by a machine. Clearly, the machine needs not to be a computer. It can be a robotic device or a set of 'smart bricks'. And the commands need not be typed on a keyboard, but can take the form of components to be assembled manually, icons to be snapped into place, and increasingly, voice, gesture, force-feedback. As Eisenberg and Buechley put it, While it is unlikely that "classical" programming will (or should) disappear, it will ultimately be one among a much larger landscape of programming styles–physical, tactile, sensually rich, athletically demanding. And as "programming" comes to suggest a different type of activity, the stereotyped portrait of "the programmer" itself will evolve (Eisenberg & Buechley, 2009. 7).

The focus in what follows is on views and uses of "programming" as a means for 1) *making things do things* (instruct a device to follow and execute orders); for 2) "*animating" things* (endow a device with a "mind of its own", teach it to "look out for itself"*);* and for 3) *"poking" things* (modulate how things act or interact by tweaking some parameters in their environment). I present settings where youngsters are asked to give and execute orders, take over control and let go of it. I draw lessons for the design and evaluation of programmable play kits for young children).

- **Programming as giving instructions: Tell it what to do!** Instructions, or directions, can be passed on verbally or cast on a piece of paper. This is usually not thought of as programming. In a program, the orders given should meet a responsive medium able to read and execute them. In other words, orders are encrypted as a series of operations to be read and run by a "smart" device. As a way of illustration, imagine the following scenario in which children tell their "smart toys" what to do.

S1 Bossing around your robotic dog. [Vignette]: *A bunch of 5-8 year olds are clapping in their hands to get a robotic dog toy to wiggle around. If they clap once, the dog wiggles its tail, if they clap twice, it wiggles it head, frantically (as if smiling), and if they clap 3 times, the dog sits down*. [Comment]: This way of bringing simple "programming" operations (in this case if-then rule) into the environment is not unlike what Eisenberg (2009) refers to as 'ambient programming.'

S2: Telling tales with Tell-Tale. [Vignette];. *A group of 4 to 8 year olds are busy telling short story-fragment into a small hand-held recording device in the shape of a ball: Five kids, five recording balls of different colours, five story-bits. Once the story-bits are recorded, the kids hook together the balls to form a "caterpillar", called "Tell-tale.* [Comment]: Tell Tale, is fairly silly. All it does is to play back a string of recorded bits, from its head to its tale. Its ingenuity, however, lays in the fact that it lets the users in, and re-combine previously recorded story bits to compose more interesting narratives. And the kids are quick to learn to improve the tale. Each time, they change the order of balls and/or record a new story-fragment. (Annany, 2001)

These vignettes show that while programming requires a responsive medium able to read and execute a set of instructions, we do not usually speak of programming if a single input triggers a single immediate response (as in ringing a doorbell or turning on a radiator). Yet we may, and many children do, if we set a thermostat to turn on the heat whenever the room temperature drops below a certain threshold, or if we set an alarm to ring at a later time, or in a different place.

S3: Setting your washer/dryer - *To a typical 6 to 9 year old: I'm not programming if I "tell" my coffee grinder to grind my coffee, or when I start my car but I AM programming when I set my washer to soak, wash, and rinse my cloth"[...] because even if I just turn a knob to start the program "it knows to do the job all the way through".* [Comment]: it is not always clear to children this age if THEY are the ones who program the machine, or if the machine itself is programmed to "respond and get itself going" as they turn a knob or pushing a button (Ackermann, 2000, Brandeis, 1992).

Programming-as-giving-instructions is best thought of as a dialogue-in-action in which a person [the child] tells, or teaches, a thing [EX: a washer] to do something [like washing laundry] on her behalf. In other words, a child delegates a job to a thing and, provided the instructions are understandable to that thing, it is going to do, on its own, what it was asked to do. The name of the game is: "make things do things". Incidentally, our own research on children and machines indicates that for children too programming is about getting a machine, computer or toy, to help you do things that require smarts. And like computer scientists, the children are sometimes unsure if the "smarts" reside in the machine itself or in the person who designed, or used, the machine

- **Programming as lending autonomy: Make it "look out for itself"**. With the avent of object-oriented and parallel distributed computing, people's views on programming took on a different tinge, which comes with its own share of underlying metaphors:
- *Metaphor 1:* From servile executant to autonomous agent: From doing things for you, the machine or smart toy is now meant do its own thing. From being a slave, it becomes a self-regulating device, or cyber-creature. It is gaining autonomy. Unlike its servile predecessor, it come equipped with sensors, motors, and all the in-betweens to help "it" see the world its own way, have its internal reference values, and optimize "its" moves accordingly.
- *Metaphor 2*: One to many: The idea here is to define an object's behaviors in terms of

attributes and methods (states, preferences, actions), and then thave different objects, each with their own attributes, interact with one another, to form wide webs, or agencies, of interconnected agents. Many emerging patterns form as multiple entities interact with one another. Imagine the following scenarios:

S4: Critters, critters, and critters! [Vignette 1]: No computers are in sight. Elementary-school children from a Boston inner-city school are building animated sculptures, vehicles and creatures, out of LEGO bricks augmented with motors and sensors, plus objects that look like LEGO bricks from outside but in fact are computational elements (flip-flops, "and" gates). One vehicle, or creature, will go towards a bright light. It has 2 light sensors to its left and right: If one is brighter, this will cause a motor to turn a wheel on its side. [Project Headlight. LEGO Logo workshop, 1986]. [Vignette 2] : Even younger children, in Reggio Emilia, build and play with funky cyber-creatures that interact with their environment and with one another. Children can build and/or influence their behaviors by acting upon their sensors and/or reconfiguring its parts. [CAB Project: http;//cab.itd.ge.cnr.it, 2000]. [Vignette 3]: Children take the programming operations into the environment to drive their turtles, but this time, in the form of bar-codes on "stickers" to be read by a program reader (Eisenberg, 2009).

Research on children and robots suggests that interacting with artifacts that exhibit self-regulating behaviors is different from giving instructions to things that executes orders. In each case the degree of autonomy of the artifact is different, and so are the children's reactions (Ackermann, 1991). To many, undoing a creature to see what's inside the black box is not the point. Instead, they focus on optimizing the dance with a creature and, in doing they experience and play out the trade-off and potential of mutual influence, and shared control. The purpose is to converse rather than construct, to attune rather than break down, to empathize rather than analyze.

- **Programming as "poking": Don't start from scratch. Make do with what's there !** More than in the past, today's computational tools and materials encourage people to program in a weak sense, by modulating rather than making, or tweaking existing programs, without ever having to produce a single line of code. Creators can import chunks of text, image, and sound [including code], which they then re-combine as they please. In other words, no need to start from scratch: You borrow what's there, and you " "remix". This shift from creating to modulating existing behaviours has important implications for education.

S7: Assemblages *[Vignette] A connected -classroom and a bunch of 8 year olds, sitting in front of their laptops. Each child is busy "writing" for a class project on Egypt (to be shared online). How do you think the kids proceed? Well here's what they do: they surf on the web until they hit some page they really like. They import the page, or parts of it, and they use it as a template that they then "massage" until it no longer resembles the "found" original or inspirational seed, but becomes their own*. [Comment}: This found art approach to writing generates big controversies among educators who wonder if children thse days (by shamelessly borrowing and tweaking) are still writing, let alone be the authors of their writings. My contention is that, provided the borrowers "massage" a template long enough, they indeed are writing! It is not exaggerated to say that there is not such a thing as writing on a blank page. The same can be said of programming (Ackermann, 2011)

From a psychological perspective, the difference is significant between using programming to instruct and obedient contraption (as in Turtle Geometry) and to influence the course of a self-regulating device by intervening in [as a part of] its own environment (as in mindstorms). And so is the difference between 'dancing" with an artificial partner and bossing around a tech-toy. In what follows, we'll see that some people are more inclined to favor one approach over the other.

Why learn to program?

If, as we suggested, programming is about giving instructions, lending autonomy, and modulating existing behaviors, the question remains: What's in it for the children? Why should preschoolers do it? In the light of the discussion so far, I can think of at least 3 reasons worth considering:

- **Mastering things: take over /let go /take over -** Through giving instructions, young children gain mastery over their world. They create and control things to execute their orders. They set them in motion, make them do things, and "boss them around". How could this not boost a 3 years olds' craving for omnipotence! At the same time, and ironically, by giving orders to an artefact reliable and smart enough to execute them, children also learn to let go and to delegate. And delegation entails distribution of control because as soon as the artifact executes a child's orders, it also acts on her behalf, by taking on a part of the job.

In a playful way, the child can explore issues of task sharing (who does what for whom) and, in doing, learn a great deal about the pros-and-cons of taking over versus letting go, so crucial in any type of transaction, be it with people or with things. Besides, even the most obedient of artificial critters, like Papert's Logo Turtle, is bound to behave unexpectedly (be non resilient) if the commands the child enters are unclear, i.e., unintelligible to 'its' kind of mind. In playing turtle, children are given an unique occasion to learn to state explicitly what they want.

- **Animating things: create / animate / interact -** By building and playing with things that act *as if they had a will of their own*, young children learn about the ways in which animate and inert objects regulate their behaviours, and interact with one another. Teaching things to "look out for themselves" and watching them do 'their' things is enjoyable because, beyond executing orders, the creatures have now gained autonomy. They can be made to follow light, avoid contact, or dance with one another. And it is fun to enter the dance with them.

In a playful way, the child learns to distinguish between self-driven and other-induced, between inner- and outer locus of control. She interacts with new forms of intelligence, different from her own and gains insights into what it means to be "animated" or "smart", for a person and a thing.

- **Modulating things: take it as is / tweak it / let it be -** More than in previous generation, today's children are often *bricoleurs* instead of planers. They are a new bread of *makers, hackers and hobbyists* eager to gather, collect, create, and trade objects, and ready to *make do with what's at hand* [1] They repurpose (remix) the stuff they find, endowing it with a second life or extra "powers". And as they grow older and perfect their technical skills, they often engage in the art of *digital* crafting and fabrication If given a chance and provided appropriate support, today's kids won't merely consume and dispose. Instead, they will create and recycle. They will care! (Ackermann, 2011)

In a playful way, the child learns to distinguish between recycling, starting anew, and adding value to what's there. It is in great part today's kids' confidence in—and knowledge about—how to fix and mend things, together with a belief in the benefits of iteration (layering, refining), afforded by computational devices, which hold the potential to bread a new culture of crafting.

[1] A bricoleur is a jack of all trades or "Bastler" in German. Lévi-Strauss depicts the "bricoleur" as adept at many tasks and putting existing things together in new ways. The Engineer, in contrast, usually starts from scratch, with an outline, and plans ahead

Who likes to program? What's in it for young children?

Not all children like to program. Not all programming feels the same. And the notion of programming itself, as debated among experts, is changing as we write.

Starting with the children, some may (on occasion and depending on their personal style) do anything to feel in charge, while others won't mind to delegate, or negotiate. Some will get a kick out of guessing and planning ahead (i.e., write procedures), while others prefer to make up their mind as they go (i,e, write step by step commands). Others yet, the bricoleurs, like to compose with what's there (i.e. borrow and edit code). In spite of these differences, it is fair to say that most children, when given a chance, will be happy to create things, or make stuff, and bring their creations to life, i.e give them 'extra powers'! Our own research indicates that children's apprehension of computational devices is at usually both instrumental and relational (Ackermann, 1991). What changes is the amount of building or "dancing" involved, the metaphors they draw from, the quality of the materials, and the play scenarios they get excited by.

For very young children, programming as modulating existing behaviors may be a way to go, although one wonders: Is this still about programming?

A program, we have seen, is more than one thing, and not all programming feels the same. Many new materials, settings, and display surfaces are at people's avail, these days, which make programming a far more informal, approachable, and natural activity than before. As Eisenberg and Buechley write: "On the one hand, a variety of traditional materials–fabric, paper–can now be employed as the background substrate for programmable artifacts and displays; that is, it is possible to work with *programmable materials*. In a similar vein, one can devise means of placing small, informal "chunks" of programs within physical environments, where they may be read or executed by mobile computational devices–a notion that we refer to as *ambient programming*[2] (…) Finally, there are novel types of *display surfaces* that may be used as the backdrop for relatively unexplored styles of programming" (2009, 1-2). These changes in turn inform the terms of the debates about the potential of programming for young children.

Our own observations of children and adolescent's uses of sensors, actuators, materials, smart bricks, and circuits (in different robot, STEM, and STEAM workshops) confirmed, time and again, that the materials used and the types of activities proposed have strong built-in 'affordances", which need to be taken seriously. For example, LEGO bricks favor orthogonal structures. One must work hard to make anything curvy. Also the do-undo-redo quality of most computational construction-kits favours *tinkering* over *crafting.* A second type of bias occurs when designers and educators impose their own limiting views on *what should* be built, and *how*. Different play scenarios excite different minds. In order to cater to personal, gender-related, and culturally related preferences, my best advise to this day is: Offer rich and diverse materials and imagine a range of play scenarios that may capture different kids' imagination, and they'll do the rest…

Lastly, I wish to echo Seymour Papert's own teachings when he advised not to teach children to program for the sake of programming. Instead, he said: use the knowledge of programming to create contexts where other playful learning can happen. Children will engage in programming if they can get something out of it right now –not later *when they'll grow up*! And this, to Papert,

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[2] The idea of "ambient programming" suggests that programs can be constructed in informal, moment-to-moment ways. One might alter the "program" shown in Figure 9 by physically messing about with cards upon the floor, changing positions and putting down new cards.

doesn't imply that it won't take much work, or effort, to become fluent at what they are doing. The implication is rather that "hard fun" is usually more challenging to the children who, we know, can spend hours on something, repeatedly, when they are genuinely interested. Thus, the question is not so much " what is the effect of programming, or using computers, on learning". Instead, we should ask: Can computational tools provide new venues for learning and play, for exploring, expressing, and sharing ideas, otherwise impossible.

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Café Philo: a constructionist tool for encouraging democratic conversation

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Abstract

A café philo is basically a French intellectual activity that takes place in a café where every patron can suggest a philosophical topic that they wish the group to argue about, describe their own experiences relevant to the topic, to support or reject with a reasons. There is a Master of Ceremonies who calls on speakers, holds them to a time limit and perhaps interacts with them to clarify points. Either the MC or a rapporteur summarizes the discussion at its end.

Richard and I believe that this kind of event might encourage more people to participate in Constructionism 2012 conversations and do so in a place that is available to all.

We also believe that this activity might answer some of the critiques about our past conferences by encouraging a greater participation by everyone.

Keywords

Constructionist talk in a public place

Evaluating Constructionism 2010 - Paris

Several weeks after Constructionism 2010, I (Jim) decided to do an evaluation of "how things went". I thought that this might help in the planning of the next conference in Athens. Perhaps I should have included a formal evaluation form in the information pack that everyone could have filled out – or not. I may or may not have been correct in rejecting this, but I decided to use a more informal data gathering system: conversations I overheard or took part in; conversations that my student workers heard (they were all master's students who had spent much time with me talking about the nature, history, literature and people who have built constructionism); direct comments to me from both irate and happy conferees; questions and comments at the plenary sessions and at the Scientific Committee meeting; comments sent to me after the conference; and lengthy discussions with Ivan Kalaš, Richard Noss and Chronis Kynigos.

As I mentioned at the opening ceremony in Paris 2010, I had hired a professional journalist who would write a report for me based on her take – as a well educated layperson – of all the plenary sessions, chats at lunch, the excursion and gala dinner. She has done this often at scientific seminars and has a PhD. And I have met with her several times and have her written report.

Finally, I read through all the conference papers and, probably, was the only person on Earth who watched the entire movie of the plenary events.

Here are some of the most-heard critiques:

- While most conferees were pleased with the change of name to "Constructionism", many questioned whether some of the new disciplines included in the conference were "really constructionist".
- Some conferees felt that *MIT folk* had too large a presence in the conference.
- Many non-English-mother-tongue conferees often felt that they were "disenfranchised" because they couldn't always follow the speed and jargon used by fluent English speakers.
- There was some criticism of the refereeing method and some people on the Scientific Committee questioned whether papers should be refereed at all!
- On rereading the papers, I noted that only a few speakers addressed the Conference theme: constructionist lessons for the 21st century and that we still lack definitions of the terms we use, especially in how we differentiate – or not – constructionism from all the other trendy pedagogical methods about. E.g. group learning, discovery learning, learning by designing . . .
- My journalist colleague said in her report that we "often come across as more of a cult than a group of learning scientists. You quote each other like quoting a kind of constructionist scripture while skirting the possibility of measuring the connections, if any, between constructionist activities (whatever they are) and deep learning (whatever that is). Where are the longitudinal and cross-over studies that even the so-called soft sciences attempt? In fact, where were all the students? I saw and talked to some wonderful young people in the workshops but never saw them on stage!"
- Because of the way we organize our conferences, the co-chairs have pretty much free hands to structure the event. This is bound to lead to some unhappiness from those who would have liked a different: conference theme, events structure, selection of plenary speakers and

papers elicited. Because *Constructionism* has no secretariat or organization behind it, this criticism is hard to correct.

Finally, it struck me that many of these critiques might follow from the fact that much of our conferences resemble instructionist classrooms rather than the interactive and loud constructionist environments where everybody is in some kind of action, some kind of *talking*; conversations are going on and topics can change and grow into others as there is less fixed structure.

My favourite part of the Seymour "constructionist mantra" that we all chant is the last bit where he says the model building that we use to attempt to make sense of our world *is done most felicitously in a public place.* That is, as a back and forth conversation about personal modelling.

Both Richard and Jim believe that a more interactive talking event at Constructionism 2012 might be both enlightening and community building; everyone is involved in topic selection and opinion giving. A constructionist community, we both believe, is something that we fear we are losing. We are not sharing and arguing about the ideas, thoughts, models that we have build over our lifetimes as constructionists. Without that kind of sharing what kind of community can we be? And, if Papert is right, how can we build effective models if we are cut off from the voices of colleagues? Reading is important but so is talking and listening in short intense exchanges.

Café philo at Constructionism 2012

Goal

As discussed above, many constructionist conference attendees felt that they had not heard those issues that they considered important or that the positions presented in papers and panels, were not sufficiently open to comment and debate. On the one hand, there always are animated discussions over lunch or drinks that went beyond the formal conference programme, but these voices were not always heard by the community - as a whole. On the other hand, conferences must be planned, and that lessens the liveliness and breakthroughs of spontaneous group talk.

Our goal, then, was to find a way to encourage any attendee who wished to suggest topics to debate to do so, and to design a space where this could happen in a democratic, spontaneous and fun way, with everyone there – while maintaining the rules of *politesse, order and clarity.* In the constructionist tradition, we will try to make an infrastructure that we could build upon, deconstruct and share.

One country's historical model: The Paris café philo

Since the 18th century, France has had a history of literary and philosophical meetings that were animated by debate, often held in a café like the Procope, with the likes of La Fontaine, Racine and Voltaire attending. Later, the American Benjamin Franklin attended. Most of us have heard of the circle around Sartre in more recent times, held, again, in a café.

In December 1992, at the café des Phares in the place de la Bastille, the philosopher Marc Sautet initiated an up-to-date café philo that was held each week on Sunday mornings. Anyone from any background or class was welcome and Sautet's charisma and flair kept talk both wild and *correct* (in the French sense, that is "polite"). Sautet died in 1998, but the café philo movement has continued and expanded both in France and elsewhere.

Most often the group determined the topic democratically, there was a *Master of Ceremonies* (MC) who kept the talk going, calling on people, restating clearly their responses so all would understand their point, and keeping individuals to a time limit. Most importantly the MC had to walk the fine line between keeping order and encouraging spontaneous – serious or wild – comments.

There was also a *rapporteur* who kept a record of the comments. Finally, at the end of the session, the *rapporteur,* or someone else appointed by her, or the master of ceremonies, who summarized the major points made in the debate and attempted to synthesize them in order state the *sense* of the session's talk. Richard and Jim will play both the MC and rapporteur.

The image of intellectuals talking, drinking and writing in Left Bank Paris cafés is one we all share. We hope to bring this form of collegial but animated talk to Constructionism 2012.

Café philo at Constructionism 2012 - specifics

- Our café philo will be organized as a plenary event so everyone can attend. It will last an hour.
- Richard has suggested several possible topics but anyone from the audience is encouraged to suggest others.
- All the suggestions will be grouped, if appropriate, into clusters, and these would be presented on a screen.
- The audience will then vote on which cluster should be explored first.
- The organizers of the session would then give a few opening remarks and review the rules

of verbal engagement

- Richard and Jim will take turns in calling on members of the community and limiting their talking time.
- If one topic cluster is exhausted, we will move on to the next.
- Finally, Richard and Jim will try to synthesize the remarks.
- Unfortunately, we can't have waiters serving coffee and drinks during the event nor can we sit on real French café chairs.

Richard's suggested topics

- What kind of a thing is constructionism? Is it really an "ism" at all?
- Do we have enough examples to refine the idea of constructionism. Or, to put it another way, What do we know about constructionist design now that we didn't know when SP mooted the idea?
- What do we know about how constructionist design maps into learning (of what)?
- Seymour's aura: how can we take matters forward without it?
- How important is theory in educational design experiments?
- How important has the idea of restructuration been since it was introduced by Seymour and Uri?
- What is Scratch (or NetLogo or …) an instance of?
- Can an event be deemed "constructionist" only if it includes technology? And, if so, what kinds of technology?

References

Google: café philosophique. You can also find the schedule of such events in France, probably in other countries, too. This will give you a fuller feeling of our proposal.

Constructionism: Changes in Technology, Changes in Purpose

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1. Introduction: A Crisis of Purpose; and Intellectual Fulfillment as a Subversive Goal

Educational technology–like the field of education in general, and many other global institutions–seems to be in a state of crisis, or at least a state of highly volatile change. The rapid advent of new systems and devices–social networks, cloud computing, fabrication tools, the Arduino and its cousins in the realm of embedded computing, just to name a few–offers tremendous creative opportunities to our field, but at the same time leaves us, collectively, with a painful reassessment of purpose. What do we want educational technology to look like; or maybe, more importantly, what do we want learning, childhood, and adult life to look like in this strange and disturbing political, cultural, and even meteorological era that we appear to be embarked upon?

There are certain stock images and phrases that one hears repeatedly in the field of education–at professional conferences, in political speeches, and in position papers–that are doing us no good in this regard. These include the notions of "invisible technology", "replacing the sage-on-the-stage with the guide-on-the-side", the "wired classroom", and numerous others that, whatever their merits in the abstract, have over time become so unquestioned, so reflexive, as to stunt our collective imaginations. Perhaps the most prominent–and problematic–of these stock notions is reflected in the phrase "skills for the 21st century", or words to that effect. Repeatedly, we are told that "we need to teach children the skills that they're going to need for the 21st century," or "kids need a 21st century education for 21st century skills", or we're asked "where are children going to get those 21st century skills that they need?" This phrasing, with its underlying grim connotations of relentless global competition and mass poverty (in the absence of those much-needed skills), is a depressing mainstay in educational technology rhetoric.

The goal of this (somewhat informal and polemical) paper is to offer several still-nascent reflections on the crisis of purpose in educational technology, and to suggest a variety of themes that could prove a salutary counterweight against these unexamined reigning images that blinker our field. There is really a double meaning here to the words "crisis of purpose", since the words apply to the professional field itself–the researchers, designers, and educators who represent the field of educational technology–and to the children whose lives are continually shaped and affected by the technology with which they grow and interact. We need new purpose as educators and designers; and to discover that purpose, we need to re-imagine the purposes that children might have for themselves.

To pursue this theme for a moment, let's return to the last of those phrases mentioned above. There is in fact a very good argument to be made that children don't really "need skills for the 21st century". Indeed, that phrase conjures memories of Aesop's fable of the grasshopper and the ant: in this case, the child's (ant-like) role is to fill up his or her cognitive storehouse of "skills" during the summer of youth in order to unpack those skills during the coming 21st-century winter of adulthood. It's an unhappy picture, and there is no particular reason that a child should want to buy into it, even if he or she understands it. A much happier starting point–rather than speaking of a repertoire of skills–is to say that children need something approximating a purpose of their own: a project, a goal, a narrative that offers the possibility of fulfillment. Children don't need skills so much as they need (as do we all) a reason to get up in the morning, and the morning after that. A person equipped with such a purpose will, as people tend to do, acquire the various skills that they need to achieve it. A person without such a purpose may garner dozens and dozens of skills, and spend long months and years in joylessly employing them.

What do these reflections suggest for those of us interested in designing technological artifacts for children? First, and clearly, they suggest that we should not think of our primary role as "skill trainers". Certainly, there are useful technological artifacts that (e.g.) serve as tutors for various skills–for solving physics problems, or rearranging equations in algebra, or recognizing animal species–but such artifacts are inevitably limited, and play at best an occasional supportive role in the much more challenging, important, and ill-defined task of providing children with internally-understood biographies. To approach that task, our goal as designers of technology can be better described as finding *activities* for children: dignified, creative, content-rich things to do. We should think of a technological environment in the expansive sense of providing potential storylines for children to grow with. We should ask questions like "what sort of technological artifacts and environment might provide meaning to a life in mathematics (or music, or chemistry, or any other field)?" Then we should do our best to design objects, tools, settings, and social structures that provide that kind of meaning.

In attempting this sort of design, it might be well for us to admit that intellectual fulfillment is something of a subversive goal in our much-anticipated 21st century. After all, the notion of "skill training" is usually accompanied by an implicit assumption that the intent of education is to pad one's resume and by that means to find a position. This is a utilitarian view of education, and it has its advantages: it's hard to argue in contrast that the purpose of education should be to make people unemployable. At the same time, there is an undercurrent of anomie, of drift, about the utilitarian view: we want education to make people useful of course, but useful to whom, and to what end? If the goal of education is simply to find a job, then the ultimate purposes of one's intellectual life are largely ceded to one's prospective employers. It is in this sense that we need, as designers, to acknowledge, even accentuate, the subversive elements of true education. Educational technology, at its best, can be a spawning ground for the idiosyncratic, the weird, the unexpected, and the hilariously useless life project.

The remainder of this paper explores the ways in which the altered landscape of children's technology may enable us, as designers, to rethink our own and children's purposes in education. The goal of this reappraisal is to create life stories that are not merely functional, but fascinating–that is, to view education as a means of cultivating idiosyncrasy, of providing the means for achieving creative joy and frustration.

2. The Expanding Boundaries of Children's Technology, and What They Imply for Educational Constructionism

One reason that this is an opportune moment for standing back and rethinking the enterprise of educational technology is that the very notions of "technology" and "education" have vastly expanded beyond their confines of a generation ago. Up until the previous decade, anyone discussing "educational technology" was almost automatically discussing "classroom computing": that is, "education" was reflexively linked to school settings, and "technology" to the computer (particularly, the desktop computer). Naturally, there were important exceptions to this broad-brush statement–such as work in non-classroom settings like children's museums, and work with non-desktop devices like robotics kits or handheld devices. Still, at the risk of only a mild degree of caricature, the term "educational technology" has conjured a standard image of children in school settings, using computers.

Within this tradition of educational technology, the constructionist subculture has always had a close association with the Logo language and with children's programming more generally. In this sense, despite its emphasis on children's creativity and independence, and despite its deep interest in experimental and unorthodox models of educational practice, "constructionism" has tended, as a philosophy, to share with the rest of the field a focus on computing as the epitome of technology. That is, most of what might be called "constructionist" research and design has not especially challenged the default notion of "technology" noted in the previous paragraph.

The current explosion of children's technology beyond the boundaries of computing alone now suggests a more expansive definition of "constructionism"–a definition that is in some sense truer to the very idea of "construction" as an appropriate activity for children. It is because technology now facilitates a powerful culture of accessible and interwoven *physical and virtual* construction that children can now create artifacts well beyond those that can fit inside the confines of a desktop computer. Technology is now, collectively, the basis of long-term individual creation: it is the collection of equipment and techniques that permits children (and adults) to cultivate their own personal workshop. Constructionism, therefore, is now the educational philosophy that underlies the growth of a "maker culture" for children, encompassing devices and materials beyond computers alone, and accommodating settings, activities, and peer groups beyond those associated with classrooms.

The key elements of this expanded technological landscape are (a) affordable fabrication devices such as 3D printers, laser cutters, desktop milling devices, computer-controlled sewing machines, (b) accessible artifacts for embedded computing such as the Arduino and LilyPad (along with numerous related devices such as low-cost sensors and actuators), (c) a rich collection of novel construction materials, prominently including conductive threads, paints, and adhesives whose use dovetails with electronic elements, and (d) a social and informational infrastructure provided by the Web that enables users of all ages to learn construction techniques and to share, exchange, and display their ideas in a worldwide community. This list could, naturally, be expanded; but these elements are foundational in a technological shift that enables young people to "construct" such items as home scientific equipment, sensor-enabled Halloween costumes, sophisticated kinetic sculptures, personalized musical instruments, and an endless list of other possibilities.

The technological landscape outlined in the previous paragraph is not only incomplete, but it is rapidly evolving: for example, the state of personal (or child-friendly) 3D fabrication is already much farther developed than it was only two years ago. For the purposes of our own community as educational designers, it is important not only to *acknowledge* but to *drive* this evolution and development–that is, we need to articulate how technology such as 3D printing *should* look in the future if it is to be a useful and expressive medium for children. We need to design novel devices, hardware, materials, software, and social structures that make (e.g.) 3D printing, microprocessors, conductive threads and paints, and so forth meaningful to children's lives and work. The history of home computing in the closing decades of the past century–and its occasionally frustrating evolution from an earlier world of giant mainframes and laboratory minicomputers–suggests that the cultural translation of technology to children's worlds is not automatic. We, as designers, should not simply expect an all-wise technological marketplace to turn its attention to children and to learning; these are developments that we ourselves need to undertake and spearhead.

In thinking along these lines, we need to bring that central question of children's purpose to the fore. How, for instance, might we design 3D fabrication devices that answer to children's projects–things like designing elements of costumes, or charm bracelets, or model cities, or dioramas? How might we design devices and techniques to introduce children to the types of (often daunting) three-dimensional modeling that accompany fabrication projects? How might we design embedded devices–sensors, actuators, and processors–that "fit well" with a wide variety of children's projects, ranging from giant-sized playground constructions to smaller-scale robotic creations to tiny wearable objects? How might we design safe, creative "smart" or conductive materials that work as flexibly in children's crafts as the long-time "classic" materials such as ribbon, yarn, and beads? How might we create social networks that support values of perseverance, tolerance (but not passive acceptance) of failure in construction, and creative growth? These are the kinds of design tasks appropriate to a focus on finding purpose in an era of "expanded constructionism". Again, rather than worrying about skill-training, the goal here is to create challenging, rewarding, and expressive ways for children to spend their time.

One additional point to make in this context is that, because the "technology" part of "educational technology" has expanded so dramatically, it has driven an increasing reappraisal of the "education" portion of the concept as well. Rather than focus on classrooms as sites of learning, the advent of tangible construction suggests experimentation with "maker spaces", community labs, and home workshops. Portable and handheld devices offer possibilities for educational activities that take place in museums, in city streets, in playgrounds, and in parks; and (the most dramatic of all these changes) the advent of learning communities over the World Wide Web enables educational communities and exchange far beyond (and often very distinct from) those associated with the classroom. In short, we can now envision educational scenarios whose settings and structure are very different from the "classic" picture. Instead of a room, we might begin our imagined scenario with a child in a setting such as a farm, or the roof of an apartment building, or a national park; instead of a school course that plays out over a semester, we might envision certain activities that play out over an hour while others play out over a period of years or decades; instead of a desktop computer, we might envision myriad tiny programmable devices of a wide range of sizes and purposes; instead of a pencil and paper (or typing at a keyboard), we might envision children working (via fabrication tools) with wood, acrylic, conductive ceramics, and numerous other materials. The two terms joined in the phrase "educational technology" move in tandem, advances or experiments in one allowing for related movement in the other.

3. Three Central Tensions for the Future of Children's Technology

The previous sections might justifiably be accused of "technological optimism"–a view that focuses on the best or most exciting features of novel technologies, and imagines (or tries to imagine) the most benign possible future that could emerge from those technologies. Perhaps it is simply human to harness one's hopes for a better future–especially where children are concerned–to changes in technology. At the same time, it is worth noting several prominent "tensions"–dimensions along which debate are likely to be framed–that are likely to be highlighted by the coming era of expanded constructionism. These tensions are in fact not at all new; they reflect ancient, complex, and perhaps ultimately irresolvable polarities that govern children's learning and adult lives. Still, the evolution of educational technologies will likely place these several tensions in a new and starker light.

Tension 1: The private and idiosyncratic versus the public and collaborative

Much of the current rhetoric in educational technology focuses on the (very real) effects and benefits of collaborative work and new social structures for children. Children are able to (e.g.) share and remix programs, display photographs or videos of their constructions on various "maker community" websites, take any of a burgeoning number of online courses, and watch educational videos. The World Wide Web is at the center of these social and collaborative innovations, and its potential for altering the map of education (e.g., for providing viable alternatives to the traditional classroom social structure) are quite real.

At the same time, many of the innovations discussed in the context of this paper–3D fabrication, embedded computing, crafting and construction with novel materials–have a private, solitary dimension to them. Technology is not only about supporting groups of people in collaborative work; it is also about providing the means and time for long-term, patient, solitary work as well. The new breed of technologically-supported workshop, and the new breed of constructionism, needs to steer a careful path between the benefits of company (creating for an audience, learning from friends in a community of builders, asking for advice from experts) and the benefits of solitude (reflection, patience, and the development of an idiosyncratic, personalized vision of one's own construction work). A workshop is, at times, a solitary, quiet place; but even in its quiet moments it is representative of an outside community of practice.

What this means for constructionist education is that, for those children who follow a strange and unscripted path to their own fulfillment–designing their own musical instruments or compositions, creating sculpture in novel materials, adventuring into their own realm of scientific experimentation–there should be the means for giving them time and privacy, and means for providing the occasional dose of social approbation and support. The new technological landscape highlights the polarities of solitary (and sometimes lonely) creation on the one hand, and collaborative (and sometimes therefore too shallow) creation on the other.

Tension 2: Control, order, and mastery, versus wonder, passionate chaos, and lunacy

Those of us who are interested in the general field of science and mathematics education are unfortunately prone to a particular fallacy. We tend to believe that, because we wish to help children find an approach to rational thought, there must be rational means to that end. We believe that there must be a "science of science education", and that children come to reasonable ends via reasonable means.

In fact, experience and numerous biographies show that children do not become interested in mathematics or science for particularly rational or utilitarian reasons (e.g., to "learn skills for the 21st century"). Instead, they come to these fields through the same personalized, idiosyncratic, aesthetically motivated, emotionally overwrought, largely irrational pathways through which people come to other fields such as music and art. A child might wish to learn science to show up a bully among his peers, or to outshine a stellar older brother, or to set a good model for a worshipful younger sister. A child might spend time building apparatus to impress her parents, or delve into the local woodland to get away from her parents. Perhaps most hopefully, a child may develop an interest in science out of an aesthetic calling: staring upward at the night sky to feel that rush of insignificance in the universe, or gazing downward at an anthill to experience both a sense of anxiety and biological comradeship.

Much of current educational rhetoric, as already noted, focuses on images of mastery and control–the acquisition of skills, the development of professional identity, the accretion of factual knowledge. Admittedly these are recurring and often important elements of education, particularly in the sciences and technical fields. At the same time, the new technological landscape enables–or should enable–us as designers to create artifacts and systems that recognize the individual, the passionate, and the strange side of every successful educational biography. These two themes–the Apollonian side of education (with its emphasis on rational goals and scientific progress) and the Dionysian side (with its emphasis on the passionate, the unexpected, and the personality of the outlier) are both elements of a new era of constructionist design. We can create crystalline, Apollonian programming languages, courseware, and instructional websites; and enable Dionysian projects such as the creation of otherworldly kinetic sculptures, computationally-enriched ventriloquist dummies, humorous musical instruments designed to be played by three people at once, and a myriad other possibilities. Both reason and lunacy are essential elements of educational design and practice.

Tension 3: The abstract and ethereal versus the messy and physical

In the early days of educational technology, designers and researchers focused on the desktop computer as the archetypal instrument; and they tended to devote their rhetorical attention to the themes of abstract computation. Thus, we would hear about the ways in which computers promoted new symbolic representations, or complex scientific simulations, or experimental mathematics, or (as the Web came into prominence) of collective minds and virtual communities.

All these elements remain important in the current technological era, and all have an important place in a rethought version of constructionism. Programming languages do indeed give rise to novel symbolic understanding and notations; simulations do enable us to approach scientific phenomena is powerful ways; virtual communities and worlds do exhibit many advantages not found outside the realm of the computer. Again, however, the advent of technologies for physical creation allows us to return to a deep appreciation for, and satisfaction in, the natural and engineered worlds of "real life". There are features of natural environments, physical constructions, and hands-on activities that simply cannot be imitated, replaced, or superseded by the virtual world. Children live in physical rooms, surrounded by their own constructions, decorations, and souvenirs; they trade and collect physical objects, which then become the currency of informal classroom economies; they give and receive physical gifts. The ability to construct with a vast arsenal of novel techniques and materials should now reawaken our interest, as designers and educators, in the integration of and distinctions between the symbolic (abstract, "virtual") and tangible (messy, material-based, "hands-on") realms. We can create programming languages and virtual communities geared toward physical creation; we can imagine construction projects that blend virtual and physical elements in all sorts of unexpected ways; we can control physical objects via symbolic commands, or use handmade physical objects as new types of input devices for computational worlds.

Conclusion

For people interested in education–indeed, for all human beings–there is much to be nervous about in the coming decades. There are profound questions about resources and their availability–water, energy, living space–in the near future; there are predictions (not always implausible) of various types of economic, geopolitical, and climatological catastrophes; there are uncertainties about how technologies will affect (and perhaps disrupt) institutions such as higher education, medicine, and the arts.

In such an uncertain, and nerve-wracking, time, the role of educational designers should be not to serve established power in any form, but to promote optimism. The coming century may indeed be a tough one for us and for our children to get through; but there are sources of joy and intellectual wonder for people to achieve as well. The goal of the constructionist community should be to create examples, artifacts, tools, techniques, and social support structures to give ourselves, and our children, continued sources of personal pleasure and reasons to hope.

Acknowledgments

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Constructionism and the confirmation of a reluctant constructivist*

or

Why, in American mathematics education, talk of constructivism is "out," talk of constructionism never really happened, and it might not really matter anyway

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I come to bury myths, not to praise them.

Preamble

There's real physics, theology, mathematics, psychology, biomedicine, and the like, and then there's the pop-culturization of these disciplines. Our culture finds a certain appeal in (the pop-culture image of) chaos, the uncertainty principle, Freudian slips, black-holes, hormones, and so on, and uses the "explanatory power" of these ideas without much concern for the depth or context of their original meaning. People use "grew exponentially" just to mean "got really big" and "Freudian" just to mean sexy. Piagetian terms like "conservation" and "stage" are invoked in education quite casually mixed with "reinforce" and "reward" from Behaviorism.

It's easy to dismiss pop-culture as just low-brow, but I think that what's really at play is a natural adoption of ideas from one culture by another because they are useful, and the subsequent adaptation of those ideas to suit the new culture and new use. That happens even in science. Freud was studying new phenomena in a new way, and invented some completely new terms for his discoveries, but also needed a broader language and set of ideas to explain these phenomena. He certainly never believed that emotions, electric charges, and pumps were the *same*, but found the ideas from fluid dynamics and electricity *useful* enough to adopt and adapt the terms. Psychology today similarly draws many of its images and terms from computers but *adapts* them. In the case of pop-culture, it is useful to have a term for startlingly great growth, and *not* useful to worry about whether that growth is or is not really what a mathematician would call exponential. And it's culturally useful to be able to wink at "meaningful" slips and have a word to call them by without having had to study the entire field of psychoanalysis.

In American education literature, mathematics may be the earliest and most visible discusser of

* I'd thought regularly about the central event of this essay—an event involving my second grade students in late 1968—for a full twenty-five years before I could write it up. Then, awakening in a jetlagged daze at the home of Richard Noss and Celia Hoyles, I wrote the first draft of this essay in its entirety, all in one morning. Thirteen years later, that version was published in Rosamond, F. A. and L. Copes, eds. Educational Transformations: Changing our lives through mathematics; A tribute to Stephen Ira Brown. Bloomington, IN: AuthorHouse. 2006. Nearly two decades have passed since the original writing. Those second graders are now 50 year olds and I'm still learning from them. This significantly updated essay reflects that learning. Thank you, "kids."

constructivism.[1] Unlike some of the other terms, "constructivism" (much less "constructionism," which I'll get to at the very end of this essay) has not become a pop-culture word in the broader world. Too boring. In the smaller world of education, its rather specific meaning was pop-culturized to the point that it seemed to be a kind of religious or political persuasion. It is not. Despite the title of this essay—which, like any title, was selected to intrigue more than edify—it makes little sense to regard people as constructivists in the sense that they might be Italians or Masons; it is equally silly to ask if people "believe in" constructivism just as it would be silly to ask if people "believe in" quantum theory. Quantum theory and constructivism are theories, and accepting or not accepting these theories is (or should be) a matter of reason, not faith.

Neither does constructivism dictate how one teaches. Though I find no alternative to accepting the theory of constructivism, I use all the tools a reasonably flexible teacher might use (within the limits of my skills): hands-on play, lecture, demonstration, exploration and discovery, listening and responding to kids' theories—everything from sage-on-the-stage to guide-on-the-side, whatever my best (but fallible) judgment tells me might meet the needs I think my students have at a particular moment.

In the classroom, I find myself more clinician than theorist, making spur-of-the moment decisions that are more art than science. But I also find a use for theories of how people learn. They help me *think* about my teaching when I have the time and luxury to do so. Constructivism is one of those theories. This essay is neither a sales pitch for constructivism, nor a critique of it—just a clarification. In fact, these days, the word, itself, is "out," at least in the U.S., too much of a red flag. Theorize as you wish, but don't ask and don't tell. So, let's just understand the theory of learning, and forget the "ism."

Why reluctant?

Life would be very much simpler for me—as teacher, and, even more so, as curriculum writer—if I truly believed that I could place my ideas in your brain. But I don't believe I can do that. The only one with access to your brain is you. Worse yet, I don't even believe *you* can put my ideas in your brain! The only ideas you can put there are your own—ones you build yourself out of the raw material around you (including, of course, what you make of me and my ideas). For a person dedicated to helping people learn, this leaves me with far less control than I'd like. A miserable state of affairs!

So how did I come to hold such a damnably inconvenient theory about learning? I did study Piaget, and loved it, but that's not what gave me that theory-that-needs-no-name. Looking back on it now, the evidence throughout my teaching career has been so overwhelming that I could not reasonably have maintained any *other* position. Even so, one story has always stood out, certainly for its poignancy, and also as the *coup de grâce* that confirmed me as a (reluctant) holder-of-that-theory. The events of this particular story have nothing to do with mathematics, except for the irrelevant detail that I happened to have been helping Jessica with some arithmetic when the climax hit. But I'm getting ahead of myself.

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[1] The word was still pretty new to us in the early 1990s, but the idea was familiar and well understood in Europe long before we got hold of it. As with most fads, the fervor is now over (and hopefully, so are the exaggeration and misuse of the underlying ideas), but the *real* ideas behind this theory remain and are still worth understanding and considering.

Swear words on the wall

It was late 1968 or perhaps early 1969, a time when riots were fresh in memory and when assassination was beginning to feel like a movement. It was a time of social fervor in many sectors: in education with the new mathematics, in social structure with feminism and Black Power, in politics and policy with the anti-war movement. In Chicago, where I was then teaching second grade, we had just gone through the traumatic summer of the Democratic convention.

Children always do things for their egos, and the story I'm about to tell might as easily have happened at any other time as at this one, but the three children involved in *this* story dropped many hints that their prank was to be seen in the larger social context. Three boys—Andy, Clark, and Mark—had a little "club." Their thing was to scream *F**** at the top of their lungs, in unison, at odd intervals throughout the day. Not too often. Just when the spirit moved them.

They would also sometimes leave the inscription in foot-high letters on the blackboard when we left the room, if nobody noticed in time. And, perhaps worst, they tormented the music teacher by doing their unison yell regularly in her class. The spirit *always* moved them when they were in music.

Consistent with the times, my assistant teacher and I were Very Understanding. Not that we didn't want to stop the disruptive behavior, but, in the spirit of that era's version of political correctness, we didn't want simply to stamp on the children's faces. So we tried all sorts of silly things, like telling the three boys that they could say whatever words they liked *to each other*, but that what they were doing involved *others*, in ways the others didn't like. As if they didn't know that! What possible fun could it be to whisper F*** to each other?!

At some point, my assistant Liz had another idea, one that I would have thought just great but didn't find out about until later when I was helping Jessica with that arithmetic. Liz thought to ask the boys if they knew what their favorite word meant. They didn't. So she explained. But she added some sociology at the same time, apparently in a style that went down quite well with the seven-year old boys.

I never found out how Liz worded this for the children, but she managed to explain to them that, though The Word was slang—a vulgar slang, at that—it had a very normal and fine meaning: it was how babies were made. She gave them the technical non-slang term using two Big Words. And the sociological perspective that she added was about people's embarrassment about "personal" things like how babies are made, and their consequent tendency to avoid talking about them, or to find substitute words (the slang), and to put all the embarrassment onto the words and thus deem the words, themselves, as *Bad*.

Clark

It was Clark who came to me to confirm Liz's story while I was sitting with Jessica. He came with what might seem a perfectly innocent question—"Is it true what Ms. K said about F***?"—but to understand the import of his question, you must know a little about Clark. His singular feature in this class was that he sucked his thumb *all the time*. Even when he spoke, he would sometimes do it through his thumb. Despite the social capital that constant thumb-sucking inevitably costs a seven-year old, he was quite popular in class, a thoroughly great kid—friendly, athletic, participating, smart, and full of lively and interesting ideas.

As it is with all children, self-image was very important to Clark, but in many ways he made it clear that self-image was a particularly special and highly personalized issue for him. He would publicly—and always pleasantly—announce the ways he found of elevating his image. Black Is Beautiful, he'd say, but then he'd be sure that I acknowledged that this included *him*. (He *was* beautiful!) Or he'd go around the class and count the other black children. (This more than once got him flattened by a girl—the largest and strongest child in my class—who wanted her identity to be determined by *her* and not by *him*. She was quite undecided about which of her parents should play the greater role and so insisted she was neither Black nor White, but Tan!) Or he'd joke with me that he was stronger than I was: after all, he could give me a black eye, but I could not give him a white eye! And so on.

Sitting with Jessica

Anyway, one morning, as I was sitting with Jessica discussing some arithmetic, Clark came over and said, thumb in mouth, "Is it true what Ms. K said about F***?" He said just The Word, four letters unadorned. No "ing."

Despite the thumb, and the exceedingly low volume, I was quite sure I heard right. Jessica's expression showed she had heard clearly, too. I collected my thoughts and figured I just had to tough this one out, so I asked "What did Ms. K say?"

Clark then recounted his version of Liz's explanation, so remarkably ungarbled (either by a seven-year-old's version of sociology or by the thumb in his mouth) that I knew exactly what Liz had said. I was quite impressed at how well he explained this complicated matter to me, and my expression showed it. With hardly more than an "uh-huh," I confirmed that he'd got it exactly right.

His expression was of total awe. He took his thumb out—it was more like he let it drop out as both hands hung by his side—and he asked in a very serious tone "Why would God make me come from F***?! F*** is *bad!*" His exact words.

I have no memory at all of what I said.

Reluctant, yes, but confirmed

Liz's story seemed *so* hard to swallow, too hard for Clark to accept without checking it out. At the same time, neither did Clark reject the story without checking it out, because he trusted me and Liz. When I supported her story, he just had to go with it. But, what did he do? It was not *our* idea that he put in his head, but *his* idea. Our idea, right or wrong, was that people's feelings were the problem: Screaming this word, because of the feelings it aroused, was disruptive. Otherwise, The Word was like any other word—just a word—and neither it, nor what it referred to, was bad. But Clark already knew better. His idea—which, of course, seemed to him to be confirmed by our attempts to stop him and his friends—was that The Word was, indeed, Bad. *Everybody* knew *that*. We could not unteach what he knew for a fact. All we could do—if he trusted us to be right—was add a new fact, a new piece to his puzzle. He would be in total control of how that piece got used, and what additional pieces he would create in order to fit "ours" in. Because this wonderful child was working out special concerns about his own status, it comes as no surprise (with the aid of hindsight!) that he personalized the definition: "Why would God make *me* come from F***?!"

I don't remember my words, but I remember my thoughts well. I thought about Clark's pain, and what, if anything, to do, or say, or avoid doing or saying, to help (if possible) to *un*do the piece of ego damage that Liz and I had been unwitting partners with Clark in perpetrating.

But some of my thinking was pure awe at the power people have over what they hear, see, and understand. On the one hand, Liz had managed to be so clear that the complex details of her message succeeded in making their way into a seven-year-old's brain. This is a marvel of communication.[2] We are rarely so lucky! On the other hand, a young child—one who was even willing to listen to us and accept a story he found painful—managed to stand his ground against two adults and preserve his own picture of the world that we were trying to change. One had to respect Clark. He certainly *was* strong!

Well, there *is* a minor consolation in constructivist thinking. The hurt—serious and not to be ignored, but probably no more deep or permanent than many Clark had already suffered—was really a creation of Clark's, unlike many insults that are *intended* as insults. Our crime, if there was one, was not The Intent To Hurt, but something more like Reckless Messing With Someone Else's Ideas. But what else is teaching about?! Giving a definition, even for a loaded word, even with a piece of psychology/sociology, doesn't seem outside a teacher's mandate. The alternatives—behavior modification, pleading, threatening to call his mother, and half a dozen other possibilities—are equally susceptible to the kind of interpretation that our silly approach took.

Constructivism does not remove responsibility

I am acutely aware of the possibility (in fact, inevitability) that someone can interpret what I am *now* saying in a way that I do not intend. Here is the misinterpretation that I'm most worried about: When I say that we are in control only of what we do, not of how it is interpreted, I do not absolve us of the responsibility to think about how things are *likely* to be interpreted. As responsible teachers (or neighbors, parents, citizens, and so on), we must, of course, try to anticipate the responses—feelings or actions—that our words or actions may arouse. We cannot excuse insensitivity as "just words," and dismiss the consequences by observing that feelings and interpretations are, after all, constructed by the listener, and not our fault.

But the bottom line is that what goes into *your* head is what *you build yourself* and put there. I can, by experience, improve my chances of helping you build what I want you to; I can provide you richer building materials; and, perhaps by augmenting my words with pictures or manipulatives or other experiences, I can provide enough redundancy of information for you to find, somewhere, clear building instructions. But I cannot build the idea for you, nor can I put it in your head, nor can I guarantee what you will build.

This is messy!

The idea of constructivist learning is at odds with a theme that pervades education: the tendency, very likely born of desire for some control, to pre-digest information, package it in small pills (preferably sugar-coated), expect students to swallow without chewing, and expect them to digest it and incorporate it into their bodies (minds) without changing its form. The analogy fails, even for a pill. A pill cannot become part of you without changing, and even the way it changes is quite dependent on your personal chemical makeup. That's one reason you should not take someone else's pills!

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2 In fact, this particular kind of marvel could well be used to argue against "constructivism." It is a perfect example of "lecture" working, even with a young child. There were no manipulatives, he did not discover for himself, and the ideas that made their way into Clark's head did, in fact, include the ones that Liz wanted there.

The constructivist theory of learning acknowledges this messiness. Students, *all* people, construct their knowledge. We don't just hear; we interpret what we hear, and that's why people can hear the same thing differently. We don't just see; we interpret what we see, and that's why people can see the same thing differently. And we construct all our knowledge at all times: just as surely when we sit—engaged or bored—in rows in lecture classrooms as when we perform experiments with computers or manipulatives, and just as surely when we are pained, scared, and angry as when we are happy and confident. The constructivist theory is not, therefore, to be trivialized in statements like "discovery is the *best* way for students to learn." This theory says that there is no choice at all: Self-construction is the *only* way that people learn. Nor should constructivism be construed to mean that people must discover everything and be told as little as possible. It is frankly a wonder to me that *anyone* believes things like that. We *all* know better.

What does this have to do with mathematics teaching?

So what use *is* this theory? Why should we care whether teachers have their students listen to lectures and do drills or whether their students perform investigations with computers and other manipulatives and then talk about their investigations? If kids are just as surely constructing their ideas when they are sitting in lectures or slogging through a textbook, what difference does it make? What does this theory say for a mathematics teacher?[3]

For one thing, mathematics is about sense-making and logic. Many mathematical ideas are developed by children without any intervention from parents or teachers.[4] For a classic example—the one that all teachers know even if they know nothing else about Piaget's work—three-year-olds are generally convinced that taller glasses, even if they are skinny, contain more than shorter ones. If they like what is being served, they cannot be argued out of the taller glass, even by showing them—for example, by pouring from one glass to another—that their beloved tall glass actually contains *less*. And, if they don't like what's being served, they will scream for the shorter glass. Even if *we* know it's more, *they* "know" it's less. Nobody taught them that

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[3] I must make another confession. Whenever I talk about "theoretical frameworks" for something as messy as teaching and learning, I feel a bit uncomfortable. Like any abstraction, a theoretical framework must simplify, must ignore parts of the data in order to be truly useful. That's much like the phenomenon I discussed in the second paragraph of this essay! In education, oversimplification is almost unavoidable. When I teach, theory can help me focus, think about the complex events of the classroom, and organize the jumble of facts into a coherent story about learning. When I'm being a theoretician, I try to build more theory, or find or do other research to clarify the story, or perhaps modify or even reject this story for a better one. Unlike a mathematical theorem, whose truth rests on logic alone and is absolute—a truth that needs no connections with a physical world—scientific theory is essentially a story whose truth lies entirely in its usefulness in explaining the events we experience and lets us to predict new events in order to make effective use of our reality. Educational theory is therefore a tricky thing. As a teacher, theory does guide me some, but not completely. I often find myself doing things that don't fully accord with what I believe, not just because I'm human and can't always act in accord with theory, but because sometimes the situation frankly doesn't seem to fit the theory and yet I must act anyway. In such cases, real science would deem the theory inadequate—it failed to account for the events—but clinical practice (teaching and psychotherapy being two good examples) requires considerable art and craft-skill along with scientific principles. It makes no sense to reject educational theories just because they don't accord with all the data. They can't accord with all the data. As a result, education lives in a fuzzy world: depending on which data we care to ignore, we generate competing theories or, worse yet, we wind up with loose or inconsistent standards for judging even the theory we've chosen to accept. Perhaps I am damaging my own credibility as a theoretician by making such a claim, but it seems the only responsible claim to make.

[4] See http://thinkmath.edc.org/index.php/Early_algebra "The Algebra of Little Kids," (Goldenberg, Mark, and Cuoco, 2010) for an analysis of some of the algebraic ideas students develop on their own before they have the arithmetic that these ideas generalize.

knowledge! They invented it themselves. Over the course of a few years, their logic changes to what we'd call the adult perspective, and they become strongly resistant to arguments that, only a few years earlier, they clung to tenaciously. This is a major mathematical step, and there are many others that children take spontaneously as they grow older.

The little child's resistance to what seems like logic to us is the same as the older child's resistance to illogic. Both are trying to make sense out of what they experience, and their unwillingness to keel over and simply accept contrary arguments is a very valuable thing. The three-year-old's conclusion about the tall glass is wrong—not all answers are right—but the reason we must respect rather than trample on the child's thinking is that we *want* people to think for themselves. It might be convenient for us in the short run if children really *did* exchange their own best thinking for our set of answers, but it would be quite unfortunate in the long run.

So, one thing that constructivist thinking tells us is that we don't want to divorce mathematics learning from sense-making. When mathematical advancement requires children to discard certain conceptions and replace them with others—and this certainly happens—we must not insult the *process* that got the children to their original, inadequate conceptions by simply declaring the results of their thinking invalid and asking them to substitute those results with ideas that *we* supply. That is like what Liz and I tried to do with Clark. It doesn't work. All that tends to happen is that the "right idea"—if it takes at all—sits beside the wrong one as an add-on, a piece of mandated *illogic*. Illogic? Yes, because if the student's logical system is not yet capable of *producing* this "right idea," then accepting it is an illogical act, an example of *un*critical thinking.[5]

Instead, we can try to find a meaningful-enough situation in which the child's current way of reasoning leads to a result that the child's own logic does not accept. The child then has an unsettling dilemma, but the child's thinking is not insulted; on the contrary, it gets credit for having recognized the conflict, and it is employed (rather than laid off) in the process of resolving the conflict. Depending on the circumstances, we might even be able to intervene respectfully in ways that truly help the child use his or her own best reasoning to resolve the conflict.

Are telling and explaining *always* bad? Of course not. When students' logical systems *are* capable of producing the "right idea," then, as long as the experience of reasoning things out for themselves is not removed from them too much of the time, there is no harm in going for the efficiency of an elegant telling. I'd still like to see students' deductive systems get a good workout a fair amount of the time—not because it's the "best way to learn (some *other*) mathematics," but because building the stamina and style to puzzle things through is, *itself*, a piece of the mathematics I think students need to learn.[6] Even this latter goal might involve "telling" students things. To the extent that this goal is served best by upping the ante of what students apply their developing logical powers to, we may want to get them efficiently (but still

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5 This is not the same as saying "If the student's logical system has not yet produced this 'right idea' (but could have), then accepting it is an illogical act." If a new idea is consistent with one's own logical abilities, then accepting the idea from an outsider is not an abandonment of critical thinking: Students do not need to invent everything. But when students' own logic could not invent the new idea, we should tread lightly about asking them to accept it. A little of that experience is probably no more damaging than Clark's experience with us—an insult, but we all suffer insults and are generally pretty resilient. Too much of that kind of insult, however, gets people to give up on their own thinking, which is bad although, alas, not so uncommon.

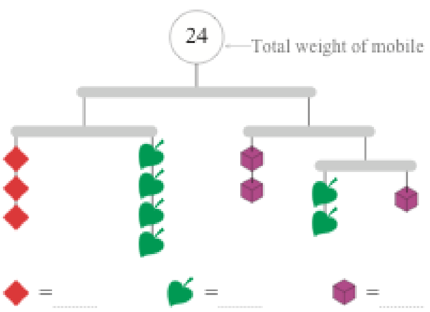
6 Note that this is not an epistemological statement: not a theory of learning, and not research result. This is a personal view of what mathematics is. If all one wants is for students to know the results of prior mathematical thinking, students may construct their knowledge from a much more predigested diet.

judiciously) past some ideas that they *could* invent on their own but that don't seem worthy of their valuable time or effort.

What about constructionism?

Another message from constructivism is about the richness of the soup out of which students construct their ideas. Lectures really *can* be excellent, even with children, if they are good enough. After all, a great movie is not "active" or "manipulative"—it is essentially a lecture with really good visuals—and it can be very effective, moving, and educational. And great story-tellers often don't even have such rich visuals. But "great" is hard to achieve, and lectures are a "thin soup." Listening, alone, may not yield as much information as listening *and* seeing. Moreover, because it *is* thin and requires intense concentration, it's cognitively taxing and so a listening-only lecture typically can't be long at all. When one manipulates some object and talks about the experiment, one not only sees and hears, but also feels and moves and creates words to explain. Perhaps more importantly, one controls what one is seeing, and is able to re-run the "movie" and "narrate it" in various ways, and hear others' interpretations, and get feedback on one's own. Building is typically social: we show and discuss what we build, and even where we do not volunteer that conversation, people *see* what we build and trap us into talking about it. The soup is just richer. There is more "stuff" in it from which to construct ideas and there is more redundancy of information. One is not so dependent on catching every detail in one way: the relevant information is available in *several* forms. More brain (whatever that means) is involved.

The thick-soup theory helps interpret the "ism" in constructionism. Constructionism could be a religion or political stand or even just a basic value, but then there's less to discuss: basic values cannot be challenged on logical grounds because they are *premises* for reasoning rather than conclusions of it. But a *theory* can be tested: does *constructing* things lead to "better learning"—darn! "better learning" needs a definition, doesn't it?—than just *consuming* things? In my work—development (construction) of curriculum—I start with the premise that constructing *is* more effective than mere consuming, but I'm quite eager to test that premise. We see that solving "mobile puzzles" like these



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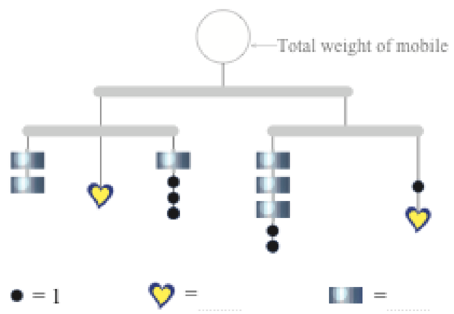

gives students a set of experiences and a platform of intuition from which they can build the logic for various algebraic "moves" that teachers often enough just deliver with little or no rationale. We don't yet have hard data that having the chance to *build* such puzzles gives students an even richer soup in which to analyze that logic, but it *looks* convincing. In a vastly more prosaic domain, solving a simple word problem like "Hiroshi has 3 marbles and Imani has 7 marbles. How many marbles do they have altogether?" may be of some value to students—note my tentative language!—but presenting the same problem *without the question* and asking students to construct good questions to ask gets much deeper analysis of the situation. Along with the question that the curriculum writer happened to think of, children ask things like "Who has more?" or "How many more does Imani have?" or "How many more does Hiroshi need if he wants as many as Imani?" or (occasionally) "Could they share that total number of marbles equally?" Having the chance to produce the same kind of language they are expected to become competent consumers of helps not only the language learning, but even the more basic recognition that one situation can *have* more than one associated question!

I give these examples to illustrate that programming a computer or building a physical structure are not the only ways to *construct* rather than just consume in some educational environment, but it is not a surprise that programming makes a special contribution. Programming involves constructing on many levels—the object/behavior one is intending to create, an analysis of that object or behavior, and the "logical argument" (the algorithm) that creates it—and making the details of that construction explicit and precise.

And what about experimentation and exploration—and, for that matter, programming a computer—in class? These are inevitably less "organized" and "straightforward" and "clear" than a lecture: they are messy[7] and make it hard to have everybody in the same place. But I'd argue that we are not really in any less control over what gets into the students' heads, anyway. In fact, we get more opportunity to guess at what might be going on in students' heads when we can watch and listen to the students as they work than when they are quiet and listening to us. If we take the opportunity and pay real attention, students' active involvement puts us (often) in a better position to interact with them. Of course, stuff goes in when we lecture, too, but it can be harder to know what that stuff is until the test, and it's hard enough even then.

The moral of this story

The story of the thinking of one clever seven-year-old illustrates that, while teaching is certainly a position of power—power that we should be careful not to abuse—it is not a position of intellectual Omniscience or Omnipotence. Would that it were that easy. As for constructivism, it opens our eyes (once again) to what has been said long before the term came into vogue: minds are not buckets. Construc*tion*ism reminds us that, while self-construction of knowledge is the only game in town, the *public* building of viewable artifacts that are sharable with others supports the *mental* building of ideas in the privacy of one's own head by being a richer "soup" for that internal learning. As for teaching, constructivism suggests not so much a *replacement* of practice as a *broadening* of practice: lecture and hands-on both make sense, and experience and good judgment (along with some *theoretical* way to think about the potential advantages and drawbacks of each) can help one decide how to use both effectively.

Do I like holding this theory of learning? That's a bit like asking if I like being human. It's not as convenient as being a god, I suppose, but it is less terrifying, and it is more consistent with reality. And besides, in neither case am I offered any choice.

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[7] This is hard for a teacher, but may not be so hard for children. Children live in a messy world and have less control of the environment around them than do adults. It makes sense, then, that they are adapted to make sense of and learn in that messy world, and to find pattern and order in whatever fragmentary and disorganized data they get. Children are constantly solving puzzles in their attempt to makes sense of the real world. This involves seeking structure, while ignoring some details. It is an act of abstraction that children naturally start with. (See, for example, Goldenberg, Cuoco, and Mark (2010), The Scientist in the Crib by Gopnik, Meltzoff, and Kuhl, and the ideas described by Stephen Pinker in How the Mind Works, a body of ideas deriving principally from research in cognitive science and interpreted in the light of evolutionary psychology.)

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The Beauty and Joy of Computing: Computer Science for Everyone

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Abstract

"The Beauty and Joy of Computing" is a computer science course for undergraduate non-majors that combines a deep programming experience with lectures, readings, and discussions about nonprogramming topics such as the social context of computing and the future and limitations of computing. The course is designed to appeal to a wide range of students, including women and underrepresented minorities. The programming half of the course uses BYOB, an extension to Scratch adding first class procedures, lists, and objects. The course has been chosen as one of the pilots for a coming (2016) high school Advanced Placement exam. Our current work includes further curriculum development, an NSF-funded teacher preparation program, and the implementation of SNAP!, a new browser-based version of BYOB.

Keywords

Computer science curriculum, teacher education, programming language, BYOB, Scratch

The Curriculum

Berkeley has a 14-week semester, and our course "The Beauty and Joy of Computing" (BJC) meets seven hours per week: two lecture hours, four lab hours, and one discussion hour. Out-of-class assignments include reading, writing, watching videos, and pair programming projects. The non-programming aspects of the course help dispel the "nerd" image of traditional computer science courses, and our course has been very successful in attracting students from nontechnical majors. The course has been taught five times over the past three years, and half of the students have been women. Almost half of the students in the top fifth of the class have also been women. Table 1 shows the topic list for the course.

This paper is mostly about the programming part of the course, but it should be emphasized that our success in attracting and retaining students is due in large part to the social context included in the curriculum. Our textbook is *Blown to Bits* (Abelson *et al.*, 2008), which presents some of the social issues of the Internet era in a style that manages to be both accessible to lay readers and deeply informed by specific technical issues. The book, like our course, is generally positive about computer technology, while including a critical appraisal of unexpected consequences.

BYOB (Build Your Own Blocks) was presented at Constructionism 2010 (Harvey and Mönig, 2010). It is based on Scratch, a language designed for 8–12 year old users at MIT (Resnick *et al.*, 2009), using a novice-friendly drag-and-drop interface, eliminating many of the difficulties beginners experience in editing a program text. Our extended version adds capabilities intentionally left out of Scratch, most notably first class procedures, so that we can teach recursion and higher order functions.

Week	Lectures	Labs	Discussion
1	Abstraction	Broadcast, Animation, Sound	Welcome
2	3D Graphics, Video Games	Loops, Variables, Random, If	Computer Anatomy
3	Functions, Programming Paradigms	Procedures, Lists	Video Games (social implications)
4	Algorithms, Order of Growth	Lists, Algorithms	
5	Concurrency	Complexity, Concurrency	Complexity
6	Recursion		
7	Social Implications, Recursion	Recursion	
8	Social Implications, Human-Computer Interaction	Recursion	Social Implications
9	Game Theory, Industry Guest	Applications that Changed the World	Midterm review
10	Artificial Intelligence, Applications that Changed the World	Online Midterm	Artificial Intelligence
11	Lambda and Higher Order Functions		
12	Distributed Computing, Academic Research (guest lecture)	Distributed Computing	Lambda, HOF
13	Limits of Computing, Future of Computing	Project work	Open discussion
14	Cloud Computing, Summary	Project, Online Final	Final Thoughts

Table 1. Beauty and Joy of Computing curriculum

All of our course materials are available free of charge through the course web site (`http://bjc.berkeley.edu`), including lecture videos, Moodle-based lab units, the BYOB software, and even the textbook.

Advanced Placement "Computer Science: Principles"

In the United States, curriculum policy is set by each local school district (each city, roughly), with some input from the state governments. This makes a widespread curriculum reform much harder to implement than it would be in a country with a national education policy. The only *de facto* exception is that secondary schools can offer university-level courses through the Advanced Placement (AP) program run by the College Board, a private non-profit organization. To ensure uniform standards, students get AP credit by taking a national standardized AP exam. Changes to the exam are publicized in advance, and so the change is promptly reflected in every school, without a complicated reapproval process.

There is a Computer Science AP course, which consists entirely of Java programming at the level of a first semester university course for CS majors. Java, which is both syntactically and semantically complicated, is probably not the ideal first programming language for non-specialists. And, indeed, Computer Science is by far the least popular AP course, and the percentage of students taking AP CS has been flat while other math and science AP courses, also traditionally unpopular, have grown dramatically in recent years (Figure 1). Women and minorities, especially, have avoided AP CS.

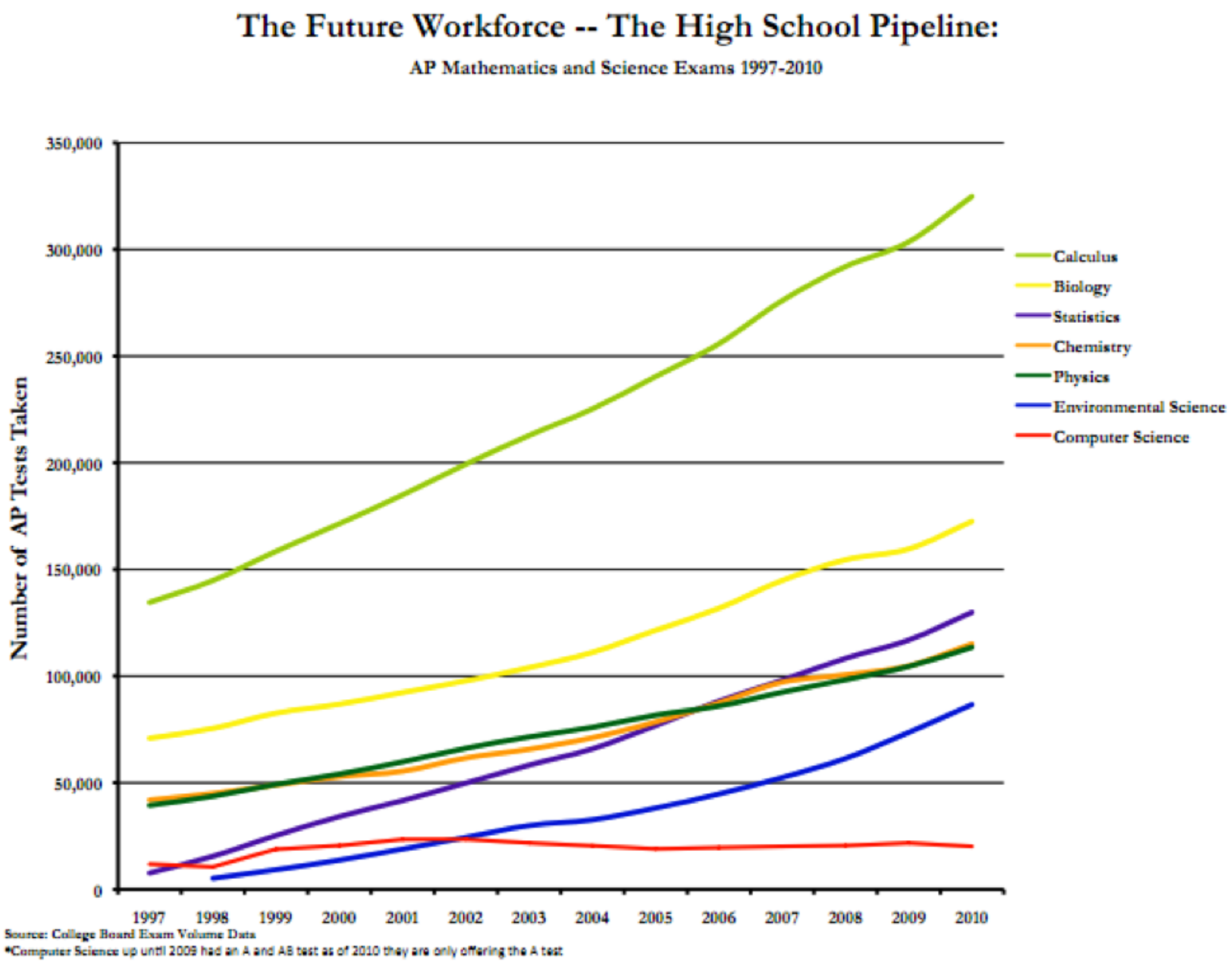

Figure 1. Advanced Placement test takers by subject.

Before the Internet and mobile computing platforms, computers were used by specialists, and the unpopularity of computer science was unsurprising. But most young people today are adept at computer gaming, social networking, and online media. Sites such as YouTube and Flickr have made young people creators, not just consumers, of online media.

Because the number of university Computer Science students has not kept up with the demand for computer programmers, the National Science Foundation (NSF) has initiated several efforts to make CS courses more popular. They are focusing on the secondary school level because students' choices are often already made before they attend university. As one part of this focus, the NSF has teamed with the College Board to develop a new course, "AP CS: Principles," that will be equivalent to a university breadth course for non-majors, rather than a first course for majors. (The old AP CS will still be offered.) (*CS Principles*, 2012.)

The new curriculum is still in development. There are design documents, including a list of seven "Big Ideas" (programming is one of them) and desired skills outcomes. The College Board chose five pilot sites in 2010–11, and 20 more sites in 2011–12. Each site is teaching its own course design, with a range of programming environments, and indeed a range in the extent to which programming is part of the curriculum at all. We were one of the initial sites. Another initial site, the University of North Carolina (UNC) at Charlotte, also chose to use a modified version of our curriculum.

Compared to the published College Board course documents, our version is technically ambitious; we think we can teach recursion and higher order functions to a general high school population (or at least to college-bound students). And we think that these powerful ideas *are* an important part of the beauty of computing. Seeing the complexity of a fractal tree, and then seeing the simplicity of the recursive procedure that draws it, is an "aha! moment" you don't get from doing a Google search or making a poster in Photoshop, or even from writing computer programs with no control structure more powerful than a loop.

Can Constructionism Be Standardized?

In the Berkeley BJC course, 30% of a student's grade is based on midterm and final programming projects, chosen by each team of two students. (Another 15% comes from an online component of the midterm and final exams, so programming practice counts for almost half of the overall grade.) The semester ends with a "show and tell" session in which student teams present their projects to the entire class. These projects are what give the course most of its constructionist flavour, although students' written work is also a public artefact in the form of a course blog posting.

In this early pilot phase of the project, evaluation standards are up to each participating school. But when there is an official AP curriculum, it will be measured entirely by an exam, which, the College Board says, will be "language agnostic"; that is, no particular programming language will be used. Instead, programming *ideas* will be tested in the form of pseudocode.

Our own implementation of the course will not change. But we are hoping to spread our curriculum, including its programming-heavy aspects, through the medium of the AP. A focus on student-chosen projects doesn't fit well with a standardized test. Can we influence the coming AP test so as to encourage a constructionist approach in high school computer science? Or is "taking over the world" through the AP a Faustian bargain in which only factual knowledge (including knowledge about programming) will be emphasized in the secondary schools?

Even at Berkeley, we struggle with testing student mastery of a visual, rather than textual, programming medium. It's hard for students to write BYOB programs in a test booklet. Our solution has been to test students' programming ability in the lab, so that they use computers to write and submit their answers. (In the written half of the test, we can include pictures of programs and ask questions such as "find the bug in this program" or "draw the picture that this program would draw.") But a nationwide test can't rely on hands-on computing, both because of a lack of available computers and for fear of cheating.

More broadly, the entire AP program is a stressful, jumping-through-hoops experience for high school students who want to attend a high-ranked university, hard to reconcile with any humane approach to education, let alone Constructionism. In the past, students with a strong interest in a particular subject might take one or two AP courses. But today, college admissions officers expect applicants to have taken every AP course offered at their school; many students' high school experience is entirely AP. A computer science course offered as an AP will have to be very joyful indeed to excite students' enthusiasm.

Teacher Preparation: CS10K

One reason that not many students take the existing AP CS, besides the curriculum itself, is that many schools do not offer it, because they can't find qualified teachers. Anyone who can program computers well enough to teach the course can get a better-paying job programming. And young people who discover in themselves an interest in programming don't often choose the kind of education that leads to a teaching credential. The NSF, in addition to the CS: Principles curriculum development effort, is sponsoring a drive to prepare 10,000 high school computer science teachers qualified to teach the new course. Many of these will be existing teachers of computer applications or, in some cases, teachers of computer assembly and repair. (In many parts of the country funding for computers is more readily available through vocational-track budgets than through academic course funding.)

UC Berkeley and UNC Charlotte have been funded by the NSF to prepare teachers through summer workshops using BJC. We ran one pilot workshop in 2011, and are funded for five workshops with 20 teachers each during the summers of 2012–14. We've already scheduled three workshops this summer (2012) and are seeking additional funding to expand the program.

School districts or other regional groups that organize 20 participating teachers can apply for a workshop. We bring experienced workshop leaders to these locations. Each six-week workshop includes an initial week of face-to-face meetings with leaders and participants, followed by four weeks during which the participants take our online course from home (watching the lecture videos and doing the online lab work) with one weekly discussion meeting in which participants gather face-to-face and work with a Berkeley teaching assistant using Internet videoconferencing. The sixth week is again face-to-face and focuses on how teachers can translate the curriculum to the specific conditions (contact hours, student body, and so on) at their schools.

Bringing the workshop to the participants' location is important. During the 2011 pilot workshop, we had some remote participants who used videoconferencing to join the group, and in post-workshop surveys, both those remote participants and the local ones found that the necessary technology was a distraction, and, more importantly, the remoteness of some participants interfered with the bonding and collaborative work even of local participants, who reported that they felt guilty if they got together outside of the scheduled session times without the remote participants. Ideally, we would fly our teaching assistants to the workshop locations, but doing that four times for weekly half-day meetings would be very expensive, so we are trying the compromise of having the actual participants physically gathered together but with a remote TA.

During the four-week online course, we provide online assistance with the lab work. The BJC course at Berkeley has attracted a small army of course veterans who are enthusiastic enough about the course to volunteer their time as lab assistants, so we can help summer participants at very small extra cost.

SNAP!: An Online Reimplementation of BYOB

BYOB was implemented as an extension to the actual Scratch source code, written in Smalltalk. Scratch was designed with the goal of maintaining a responsive graphical user interface, and smooth animation of sprites, rather than with the expectation of composition of functions as a primary control structure. The result was a series of incremental modifications to nearly every part of the code. Scratch's lists were designed for iterative sequences of commands, not for building up with recursive reporters. These and other factors made BYOB projects very slow, and debugging BYOB difficult.

BYOB's developer, Jens Mönig, is currently working on a complete reimplementation, written in Javascript so that it will run in a web browser. This solves several problems for us. Because it's a completely redone design, projects run much faster. Because it runs in a browser, the new version automatically supports every new platform, including tablets and mobile phones, although the user interface isn't currently very usable on the small screen of a phone. Also, we've learned that school IT departments are reluctant to install software they've never heard of, and a browser-based implementation requires no installation. Eventually, running in a browser will enable new capabilities, such as embedding a project in a web page. The new version is called "SNAP!"; it was renamed because a few teachers objected to the original acronym.

As of May 2012, there is an alpha-test version, missing many features, but already quite powerful, available at `http://snap.berkeley.edu/run`. (While in alpha testing, we don't promise that saved projects will remain readable as development continues. We are hoping for a stable beta version by the time of the conference in August.)

Javascript tries to maintain the security of users' computers by limiting the ability of downloaded code to interact with the computer's filesystem and hardware. This is problematic for us both for saving projects and for interacting with real-world sensors and robots. The standard Web solution to the former problem is to store everything "in the cloud," which means that we would have to provide user project storage centrally, or else ask schools to run their own SNAP! servers, defeating the no-software-download advantage. A possible solution would be an *optional* software download to interface between SNAP! and the user's computer.

Further Curriculum Development

The UNC version of the course is different from the Berkeley version, for two main reasons: UNC has fewer student contact hours per week, and our collaborator there, Prof. Tiffany Barnes, was previously teaching an introductory course based on video game design in Gamemaker and wanted to include some of that curriculum in the BJC course. We anticipate that other schools will have similar need for flexibility in the curriculum.

We therefore plan to build curriculum materials with the same core ideas, but divided into modules from which each school can select the ones they need. One big example is that, even though BYOB supports object-oriented programming through sprite inheritance, there is no OOP curriculum in BJC. A different kind of example is that we are working with a Microsoft-sponsored program that uses the Xbox Kinect motion sensor as a device to be programmed, and we plan to develop curriculum modules for that.

We are also working with the Ensemble project (`http://www.computingportal.org`) to allow teachers outside of our group to contribute modules.

This raises the question, so far unanswered, of how different a course can be from the Berkeley version and still be called "BJC." Probably the modules will be categorized, and there will be minimum standards both in the big ideas of programming and in the social context of computing.

Acknowledgements

The BJC design team at Berkeley includes its instructor, Dr. Daniel Garcia (Principal Investigator on our NSF grants), and several graduate and undergraduate students, especially Colleen Lewis, Luke Segars, and Glenn Sudgen. Dr. Nathaniel Titterton is our lead education researcher. High school teachers Josh Paley, Sean Morris, Ray Pedersen, and Eugene Lemon have participated in the development and testing of the curriculum. Prof. Tiffany Barnes is our collaborating Principal Investigator at UNC Charlotte. BYOB was developed, and SNAP! is being developed, by Jens Mönig.

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Niches for Constructionism: forging connections for practice and theory.

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Abstract

Can Constructionism afford segregation? Or to put it more positively, what is to be gained if we try to forge connectivities with the academic and the institutional worlds? In this paper I discuss some efforts for connectivity in three different domains. A wide scale Education Ministry digital space for enriched curriculum books, a constructionist kit system built on E-slate which can get students and teachers to create technically sophisticated applications and a process of networking amongst theoretical frameworks and constructs. I argue that such efforts may enable us to include Constructionism as an evolving and in flux realistic epistemology, theory and practice in a world of changing paradigms for education and for using technology.

Keywords

Connectivity, theoretical frameworks, constructionist kits, large scale

Introduction

When Constructionism was coined by Seymour Papert almost half a century ago there was hardly any other theory and practice, let alone impact, on using digital media for added educational value. Papert's concern was to align with constructivism in proposing a sense making human-oriented approach to study learning. It was however also to distinguish from it by challenging Piaget's theory to draw attention to the meanings actually generated by learners rather than to describe their shortcomings in understanding taken-as-ontological meanings at different stages in life. His agenda was further to change the perception that concrete thinking was a 'lesser' kind of cognitive process in relation to abstract thinking by pointing out that proper and rich exposure to the former was pivotal in ever hoping to reach the latter (Ackerman, 1984). Another part of the agenda was to claim that meanings are naturally generated in our social, intellectual and physical environment and that digital technology makes it possible for us to enrich this environment through constructionism so that learners would enjoy more opportunities for the formation of meanings. Papert's work has been an ode to kids' logical-mathematical and creative thinking, he has been provocative in arguing that we have not paid enough attention to how children think and to the nature of meanings they form given the language and tools they use, the activities they engage in and the communicative situations they find themselves in. He also argues that for children, a key to learning is the process of engagement in activity, the ownership of ideas and style of learning and the exposure, i.e. expressing their ideas to others, for reasons of exploration and communication.

So, what happened to constructionist theory since its first articulations? What has the constructionist community learned so far and how has it been put to use in educational practice? Has the theory been developing all these years or is it a well recognized but now rather blunt instrument associated with outdated technologies and ideas of how they can be used for learning? We live at a time of growing connectivity and resource availability, at a time where 'watch and practice' technologies and administrational infrastructures are popular and politically publicized. We are also in the midst of an era where an important part of youth culture involves the immersion in collective virtual worlds where representations designed for meaning-making are given very low priority by media designers. We live at a time where several theoretical frameworks and constructs in education are in danger of lying in fragmentation each to be used by a community of researchers close to the context from within which they emerged.

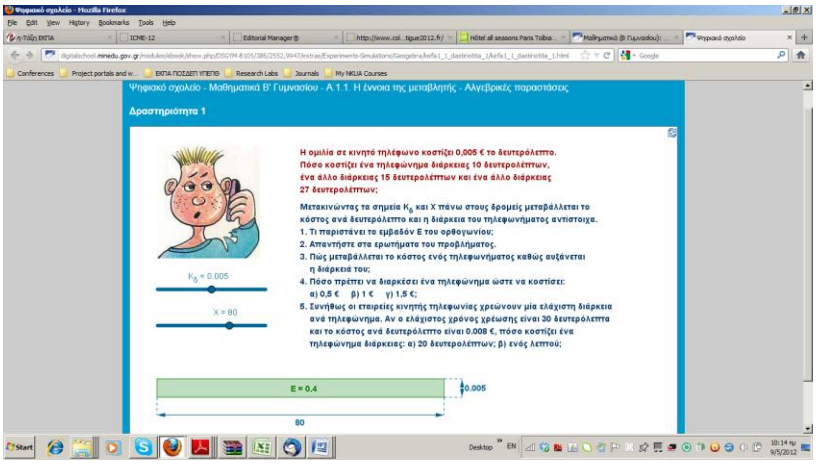
So, is constructionism relevant and useful today and in what capacity? We have seen this kind of learning in practice in many occasions, but we have seen very little in institutionalized life (Kafaii & Resnick, 1996). Does it address only the constructionists and Scratch, NETLOGO, TNG Star Logo and other like-minded communities in relative isolation from institutionalized life? Or can it be meaningfully connected to other theories and compatible practices? Is there some mutual benefit from trying to forge such connections? How can it be useful in the age of jings, blogs, portals and LMS, of reforms delivering tons of instructionist and informative material for free to lower the cost of education? Is there scope for further development of constructionist theory in an era of ever-changing technologies and a wealth of theoretical frameworks and constructs and how can this be justified? In this paper I attempt to contribute to the argument that constructionism is essentially an epistemology creating continual need for an evolving theory of learning in collectives and individually and at the same time a theory of design of new digital media, new kinds of activities facilitating the generation of meanings and techniques and processes for systemic interventions at various levels such as school cultures, resource systems and educational systems. As such, there is scope and interest in finding ways to include Constructionism in wider efforts to promote a culture of networking amongst diverse and fragmented theoretical frameworks and paradigms and top promote an distinct, transcendental and connected role for our community in a changing society which is in a continual flux and under continual challenge.

Changing trends for technologies in education

A particular kind of challenge comes from the changing of trends in what is considered as added value in the uses of digital media in education and in society at large (Papert, 2002). A first wave was the dynamic manipulation and icon-driven technologies which questioned programming as an effective meaning-making activity. Programming (not to mention the use of formal code) were seen as a kind of unnecessary noise to doing interesting things with digital media. A second was the advent of media supporting collaboration when attention was given to collective discussions and argumentation and taken away from constructionist activity as if these two were distinct. A third wave was the advent of social media, portals, LMS and the recently widely advertised 'watch-and-practice' video portals considered as an infrastructure relieving teachers of the need for frontal lecturing. This means that attention is currently given to the use of technology which supports traditional curriculum delivery so that human time and focus can be given to discussing questions and supporting the generation of meaning. So is constructionism going to be considered as an unnecessary noise to content delivery and large 'get togethers'? The problem of shifting paradigms for trendy uses of digital media in education and in society creates a need for constructionists to be able to effectively and clearly forge links and connectivities through which constructionist epistemology, media and uses are described in terms of very different points of view. In this paper however, I'd like to go a little deeper into some experiences with the processes of including constructionism in wider initiatives of networking amongst theoretical frameworks.

Micro-experiments as an avenue to wide scale deployment

This example comes from two otherwise unconnected wide-scale initiatives of the Ministry of Education in Greece. One has to do with training 650 teacher educators to give 96 hour courses on using digital technologies to their colleagues in three subjects, language, mathematics and science. This has involved up till now 14000 teachers who have taken this course. The mathematics teachers amongst them (around 1/4 of the total number) have been centrally exposed to constructionist epistemology, technologies and activity designs[1]. The other initiative is the 'digital school', an LMS - portal containing amongst others a place where the old curriculum books are being 'digitally enhanced', i.e. filled with links to places decided by academic education specialists for each subject[2]. The Ministry's agenda was to provide all students with a free service for them to access the books and to support this move they included the 'enhanced' version to differentiate it from just html files of paper books.



This was a very large scale, raw and visible intervention. It was not the place to try to portray constructionist media assuming that the educational world would just sync into a new norm for learning mathematics. The teacher education course seemed slow and arduous through this lens. So, we decided to propose a construct with constructionist potential and called it a 'micro-experiment'. A micro-experiment is a digital artefact addressing the student through text tasks including open ended questions, aimed at starting mathematical discussion in the classroom and most importantly providing specific things for them to do mainly by means of dynamic manipulation. A crucial feature of these artefacts is that even though they conform to the LMS

[1] In-service teacher training for the utilization of ICT in the classroom, Hellenic Republic, National Strategic Reference Framework, Operational Programme Education and Life-long Learning, MIS codes 217081, 217082 & 217083 (2009 - 2014)

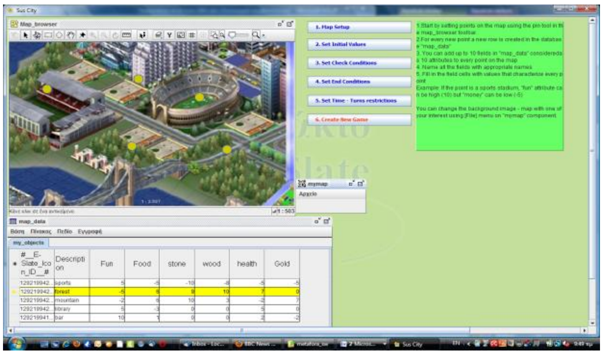
[2] "DIGITAL SCHOOL: Specifying a Digital Educational Platform, Building and Operating an Educational Knowledge Base, Adapting and Annotating Learning Objects with Educational Metadata, Building the Infrastructure to Support Exemplary Teaching Practices and the Use of the Participatory Web", Greek National Strategic Reference Framework (NSRF), No 296441 (2010 -2015)

imperatives of immediate web accessibility, they also conform to a constructionist treatment. With a double click, they download as D.G.S. files which can then be changed and dismantled at will. Constructionist activity is thus not pushed aside but instead enabled even in a context where it is not amongst the main issues forming the paradigm. Consider the scale: around 250 of these are being developed for each mathematics year book for the 12 years of compulsory education, they constitute the main type of artefact, and the site has received 3.5M hits in the last year of so in a country of 11M. It's not bona-fide constructionism. But it's a push towards constructionist epistemology, it encourages this kind of activity and this can be done through schooling. Amongst others, Blikstein and Cavallo (2002) have shown what it means to generate change in school cultures and how in any institution, focused change is slow and messy (Papert, 2002). The teacher education program in Greece will take its course in time. The micro-experiments initiative may hopefully make things a little smoother for instance by making the teacher education initiative relevant and connected.

B&W box designs for diverse constructionist activities

Several years ago I discussed the idea of black and white, or semi-transparent box designs as a means to meet students and teachers half way with respect to the quest of generating constructionist cultures and norms (Kynigos, 2004, 2002). B&W box artefacts allow for construction either through programming or in kit-style connection of digital components. The point is that users get to start with building blocks which are much more sophisticated, higher order and specialized than generic primitives. In this way, they can efficiently create artefacts which have sophisticated functionalities in themselves and thus see the point of constructing beyond creating simplistic objects such as Scratch x-mass cards or amateurish games. This is not to say that pure constructionist media should be substituted by kit like media. But I do think they should co-exist. A constructionist culture needs to be able to produce real usable artefacts with professional looking functionalities and interfaces, to see that apart from epistemology and ownership, media useful to others can be developed. In this wake, our long term project to develop E-slate and use it as an authoring system for teachers and students has taken a new twist. In the past two years, we developed the idea of E-slate 'Microworld Kits'. A Kit is a thematically cohesive artefact which operates as a sub-set of E-slate and at the same time as a fully fledged authoring tool itself. A Kit is a template with which microworlds belonging to its theme can be built by teachers or students alike. At the present, on the English 'downloads' link on the ETL site (http://etl.ppp.uoa.gr) three are four such kits. One is recognizable: 'Turtleworlds'. The others are 'Dyna-stage', 'Sus-x' and 'MaStoHF' or 'My Story'. Dyna-stage is a template for Newtonian simulations providing basic tools for the creation of graphical objects and Logo programs to give them properties, behaviours and interactions involving for instance, field forces, collision rules etc. Sus-x stands for 'Sustainable - something'. It is a sim-city like game where everything can be constructed and changed, the map, the fields, the values, the communications to the users, the 'red lines', the places to visit, the consequences of a visit. The components have been connected with the usual combination of plugs and Logo scripts but the Kit is ready for the creation and change of these games. MaStoHF is a Kit connecting geo-coded data with a timeline and allowing for TableTop - like queries and picture matching. Again, all the data can be changed allowing for the creation of investigational artefacts for a wide range of topics.

Mainly Sus-x but also MaStoHF have been used for pedagogical designs and interventions in Environmental Education (EE) where there is a distinct agenda for a shift from an objectivist paradigm of learning about environmental problems to a critical knowledge paradigm where the complex and multifaceted character of current socio-environmental and sustainability issues is explored and discussed and the underlying socially constructed value-systems, states of mind and practices are revealed and questioned (Kynigos & Daskolia 2011). This agenda can be supported by reifications of such exploration and discussion which can be sus-x games or mastohf explorations in a context where students and teachers tinker with and make changes to their own artefacts discussing the rules and functionalities.



Constructionism with B&W box designs is again not pure constructionism. But it can get outsiders to efficiently get engaged with the idea and to come up with things they can use. we have been using it in our masters courses at the ETL for more than 10 years now with student and in-service teachers of science, mathematics, language, EFL, geography, history, environmental education, ancient Greek. These people engage in constructionism themselves by designing and developing artefacts for realistic constructionist activity by students (see also Healy & Kynigos, 2010).

Constructionism and the networking of theories

Another arena for connectivities is that of theory. Reflections on the place and role of constructionism in amongst theories have emerged as a result of a wider initiative to consider the landscape of theories in the field, to better identify their nature, status and functionalities and to develop strategies for integrations amongst them so that there is a better understanding and communicability of the progress of mathematics education as a field to stakeholders outside academia and educational reformers.

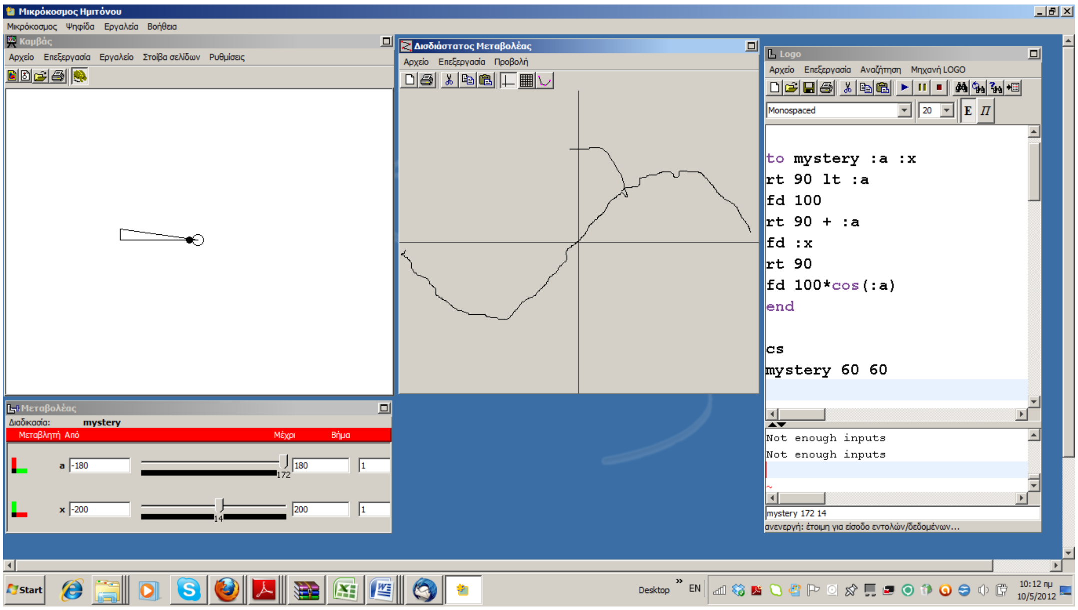
Significant work on bringing constructionism and other theories developed or shaped to study the uses of digital media for learning was done through the work of six European research teams for a period of 6 years (2004-2009, the TELMA European research Team in the Kaleidoscope Network of Excellence and the European Information Society Technologies programme (FP6) titled 'Representing Mathematics with Digital Media' (ReMath)). Mathematics Education theories such as the Anthropological Theory of the Didactique, The Theory of Didactical Situations, Social Semiotics, Semiotic Mediation, Activity Theory, Instrumental Genesis were considered together with Constructionism to be part of the same phenomenon happening more widely in mathematics education, i.e. a fragmentation and polysemy slowing down and diluting the production of knowledge in the field. The teams worked under the initiatives of Michele Artigue (Artigue et al, 2009) to elaborate a process of networking amongst these frameworks initially at the level of conceptualizing and proposing a networking process and subsequently at the level of operationalizing the process to actively articulate connectivities between frameworks through joint research. The initial framing of the networking process involved an articulation of these theories through the lens of their didactical functionality and the language of concerns. Special attention was give to the aspect of representations of mathematical concepts through digital media (Artigue et al, 2009) and the formative influences of the context of the educational system and the processes of design and development of both media and research interventions (Kynigos and Psycharis, 2010). In the ReMath project, networking involved the whole cycle of designing and developing six original state of the art digital media for learning mathematics, the design of interventions and classroom experiments and the implementations of these analyzing students' meanings in realistic classroom situations. Several networking tools were developed for cross experimentation which operated as boundary objects to identify and articulate connectivities between frames. A key element of the project was the cross-case analysis of these studies, i.e. an integrated meta-analysis or two research studies carried out by two different teams in respectively different contexts involving the use of the same digital artifact.

This section contains three examples each forging connections between constructionism and an alternative theory. The first two are from the ReMath project. The third reflects the discussions around connectivities between Constructionism and Challenge based learning, a new venture connecting Inquiry learning with CSCL for Science Education. What is particular about the enterprise of connecting constructionism with other theories is that as perhaps the oldest theory on this particular issue, it has had enough time to become fragmented largely due to its interpretation as a static theory and in parallel, enough time has passed for it to evolve and develop from a theory focusing on the individual to addressing social and distributed cognition, many types of technologies and representations, new ventures such as for instance the design of activities and interventions and most importantly interventions challenging institutions. This developmental nature has not really been recognized or noticed much outside the constructionist community and yet connectivities with at least some other theories could provide mutual benefit and reveal complementarities useful to elaborate in the future.

Constructionism and Instrumental Genesis

Take for instance the theory of instrumental genesis (Guin & Trouche, 1999). With respect to connectivity, it was originally seen as a tool to explain the instrumentation of CAS-based techniques as discussed earlier within an anthropological framework. There have also been some perceptions of IG providing a more elaborated tool to describe the process of mediation within the framework of Activity Theory. IG has given a lot of attention to instrumentation as a notion to describe what happens when digital artifacts are put to use by denoting the formation of a conceptual schema which users develop about the functionality of the artifact in question, the underlying concepts, the kinds of things is can be used for, the meaning of its representations etc. The process of instrumentation has been seen as incorporating changes made to the medium itself and this aspect has been termed intrumentalization. Instrumentalization was coined to show that the artifact itself is shaped by each individual through its use and that there is a reciprocal relationship between these two processes, i.e. that instrumentation is affected by instrumentalization and vice-versa. Little attention however has been given to instrumentalization itself. Activity theory was not articulated at a time when the medium was susceptible to functional and operational changes as is the case with digital media and therefore gave no detail into the process by which schemes of artifact use were formed through the mediation of artifacts.

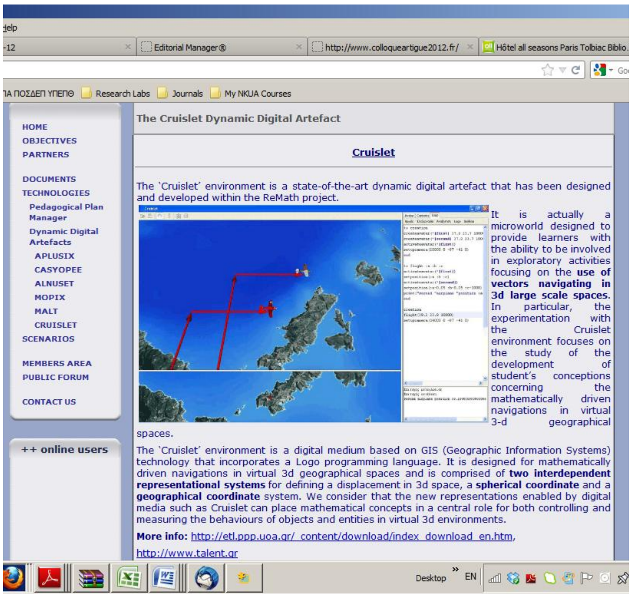
Instrumental theory identifies instrumentalization and situates this process within the context of mediation and schemes of use but does not elaborate on its definition. What is meant by changes to the artifact? What constitutes a change? What constitutes a change which is relevant to instrumentation and are there changes which are less relevant or irrelevant? Is instrumentalization a process which inevitably happens during instrumentation or does it depend on the design and the nature of the activity and on the nature of the artifact. Are there artifacts which invite instrumentalization more than others? What are the issues involving the design for instrumentalization (Kynigos & Psycharis, in press). These ideas are coherent with the notions articulated about a decade earlier by Noss and Hoyles (1996) that a medium shapes the mathematical meanings generated through its use and at the same time is itself shaped by use reciprocally. What is interesting however is that the design element of constructionist theory offers a more elaborate articulation of the process of designing media so that they afford useful and rich kinds of instrumentalization



. A relevant notion here is that of 'half-baked microworlds' developed by Kynigos (see e.g. 2007, 2010), i.e. digital artifacts intentionally designed and given to students as malleable and improvable asking of them to engage in discovering faults and shortcomings and changing them. This process is at the heart of fallibility and bricolage activity and discusses instrumentalization processes through a language of concerns pertaining to design and meaning generation. The figure in this section shows a snapshot of students' work with the 'mystery' procedure which was given to them to find the bug so that it always creates right triangle. The bug is in that angle variable :a is not connected to the second segment which is created by an independent variable :x. The students can use the uni and bi dimensional variation tools to get a feeling of what kind of relationship is required between :a and :x to create a triangle. Dragging became more and more focused, their attention being on how not to 'spoil' the right triangle. This kind of reverse engineering resulted in a periodic relationship which led students to suggest a trigonometrical function and to eventually try out the sinus function. So, the bi-dimensional tool was used to express a relationship kinesthetically through a curve rather than the converse.

Constructionism and the Anthropological Theory

Finally, a comparison between the Anthropological Theory of the Didactique (Chevallard, 1992) and Constructionism may allow for socio-constructivism to play the role of a common basis. A key issue where these two theories are complementary however, is the role and status of control of the didactical process. This may well be attributed to epistemology or simple to the notion of concern. Constructionism takes on board the notion that meanings are in anyway generated to some extent outside the control of a teacher or the sequencing of an activity. In designing educational activities therefore didactical intervention can at most aim to help create an environment rich or dense in opportunities and challenges for meaning generation. There is an element of randomness and uncontrollability in that process which needs to be appreciated if there is learning to be done. Otherwise, intense attempts to control the learners activities may result in disengagement and trying to guess what's in the teacher's head rather than ownership of knowledge. This does not mean that design is 'looser' with respect to activity sequencing, the designed tools to be used or the interactions between teacher and student collectives. It means however that the kinds of interactions are more strategic from the teacher's side, more participatory in a joint enterprise and more allowing for the unexpected. The teacher elicits meanings in formation and mathematics in use and helps students elaborate emergent ideas and generalizations. Also they allow and recognize fallibility, i.e. the status of suggestions, student created artifacts, student solutions etc to be in evolution or in flux rather than that of an expression of thought awaiting a final verdict. In this wake the construct of half-baked microworlds was developed to describe artifacts especially designed to invite changes and improvements and given to the students in that capacity, rendering them engineers (Kynigos, 2007). ATD on the other hand elaborates controlled scenarios and designs where didactical interventions are pre-designed, expectations of activities and understandings are precise and stepwise and teaching sequences are defined in terms of responses to specific pre-defined questions and tasks.



From the identification of fundamental situations expressing the epistemological characteristics of a mathematical concept or theme to the determination of the didactical variables which condition the efficiency of solving strategies or condition students' adidactical interaction with the milieu, the design of situations reflect an ambition of control and optimization. The importance attached to a priori analysis and to its anticipative dimension also attests this ambition, deeply rooted in the role of *phenomenotechnique*, with the meaning given to this term by Bachelard, devoted to didactical engineering (Artigue, in preparation).

Constructionism and Challenge Based Learning

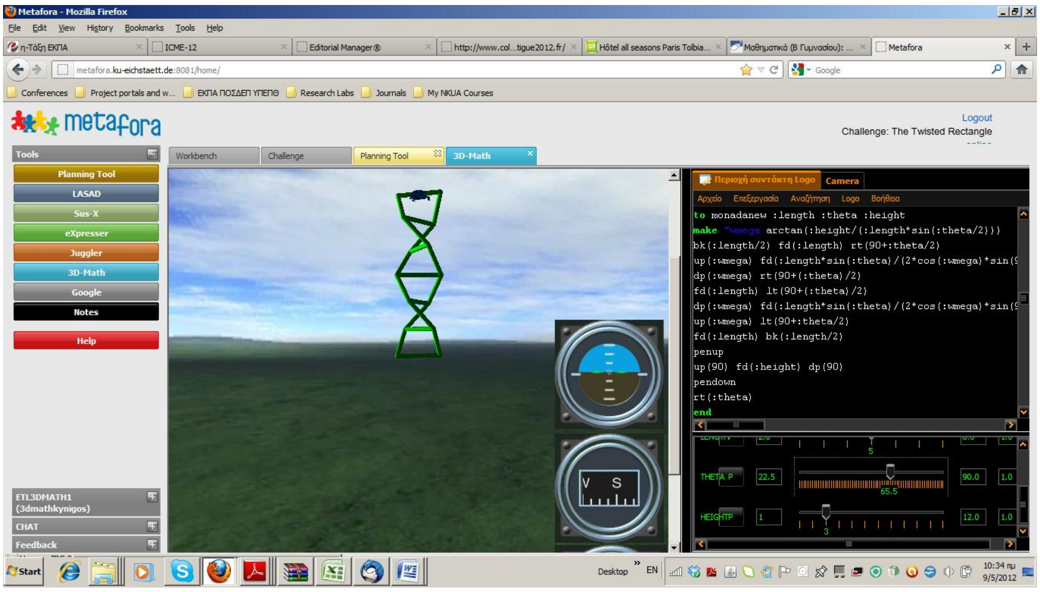
In the Metafora project, our aim was to support students' reflections on their work as a collaborating group. To look at emerging consciousness of mutual engagement, leadership, task distribution and roles. But to also study the emergence of meanings around the domain or subjects at hand. Some of the student group tasks were clearly constructionist and involved the use of microworlds to explore and generate meanings around challenging tasks. We came up against the need to think about the relationship between Constructionism and Challenge based learning which seems to be a rather recent trend emerging from an integration between inquiry learning and Scardamalia's collective knowledge aggregation learning (Scardmalia and Bereiter, 1994).

Challenge based learning addresses complex open-ended challenges which we often face in real life. These are challenges where no one knows the answer in advance, there may be multiple approaches and multiple possible solutions. Of course the uncertainty can be emotionally challenging. So, sharing the challenge often reduces the level of anxiety. The best approach maybe to explore or maybe to call a meeting and brain-storm how to go forward. Often creative new solutions and ways forward emerge. In real life there is never a teacher in the background making sure that the challenge is 'well-structured' and within our capacity to solve. Employers complain that a lot of new recruits fresh from school seem unable to cope with this reality. They have been programmed by school to expect neat tasks that they can apply procedures to solve. School-ish challenges need to be well structured so that they are not too difficult as this is found to be de-motivating for the students. So students complain when they are not given clear instructions. They can't cope with the messy ambiguity and ignorance of real world problems and so they are not capable of the creative leaps of innovation that are required. The question for challenge based learning is how can we teach in a way that prepares people to solve real authentic problems? For the Metafora project, this was the challenge of 'learning to learn together' (Wegerif et al, 2012). The focus of this pedagogy is not on a bit of Mathematics or a bit of Science that we have to teach and that they have to learn. The focus is precisely on the discomfort that they feel when faced with a complex challenge. This is what it means to have learnt how to learn - when you know how to carry on with any problem because you can break it down and make a start, explore, brainstorm etc. The theory here is basic to the inquiry based approach. Inquiry based learning should be about pursuing real problems, not about achieving pre set curriculum goals. Whenever we start with 'Maths' or 'Science' we have already failed. Real problems are not bits of a pre-packaged curriculum.

Constructionism can be about real problems but it can also be about interesting problems emerging from exploration and tinkering with digital models of real or abstract phenomena and objects. The focus is on the generation of meaning, on understanding to such depth that you can create or change a model based on the ideas and meanings at hand. Learning to learn together does seem important and challenging to Constructionist collaborations. Constructionist challenges are often complex, open ended and maybe even perceived as unclear in the sense that there can be more than one paths, ideas and constructs considered as 'solutions' etc since the point is for a collective to reach the generation of socially mediated meanings. Addressing issues of how to work together to tackle the problem, of the responsibilities taken and the communication required and of jumping in and out of meta-levels and between process and content are at the heart of learning to learn together.

So we can think of a constructionist challenge based pedagogy where specific deep ideas and concepts are not considered as artificial and school-ish. The task can be such that the conceptual field around it (to use Vergaud's definition, 1991) is artificially narrowed down so that students - communities will focus and go in depth to generate understandings and meanings related to scientific and mathematical ideas. The agenda here is for them to get an idea of doing science or mathematics themselves. Of engaging in the process of scientific thinking. Of exposing themselves to the beauties of fallibility where any insight or idea is communicated in order for it to be challenged and refuted. I think it's a question granularity. There is complexity and breadth even in clearly defined conceptual fields.

The twisted rectangle - TwR - for example (see figure below) puts together ideas and concepts of mathematics which are never associated or connected in curricula precisely because schooling is so artificial. In a mathematical 'real world' this does not happen. In the TwR trigonometry joins functions, geometry, navigation in 3Dspace, modeling, stereometry (consecutive projections on planes). So, it is designed to counter artificial structure and fragmentation in school. It is also a difficult and 'unknown' task. It is only a real world problem in that once figured out in some user inspired way, models of real world phenomena, objects and relations can be built with it. But here constructionism brings out the idea that building and improving an artifact taking the role of a boundary object can indeed be one of the techniques to get collectives to address learning to learn together aspects of their activity. This can be used both in traditional Scrardamalian contexts and in narrower contexts within designed conceptual fields. In both cases tasks which are designed to be manageable, fragmentation and the artificial nature of schooling is countered.



These are three kinds of connectivity elaborations between constructionism and other theoretical frameworks in mathematics and science education. The process of networking is perceived as essential for the de-contextualization of the theories and a better sense of the richness of theory building in the field. Constructionism is a theory which studies meaning generation through activities of collective and individual bricolage with expressive artefacts (mostly but not exclusively digital) where meaning is drawn through the use of representations, engagement with discussion and reflections on how to make changes to them and on their behaviors as they change.

Discussion

Constructionism is beautiful and worthwhile and at the same time is becoming segregated and in danger of being forgotten in a fragmented world where networking and connectivity is being recently mobilized to meet such a problem more widely. This networking should include constructionism as a distinct epistemology and paradigm of learning, as a particular kind of media use and as a design and learning theory in a continual flux. There are of course many ways of going about the problem. It is both strategic and scientific. Here, I gave some examples for constructionism to distinctly exist in pluralistic large scale contexts, in teacher education initiatives pushing for teacher as designer reforms and in collective efforts for theory networking. The question however remains: in today's world, what is distinct, relevant and transcendentally useful about constructionism? What more do we need to find out and what else do we need to design and develop? What are we learning about how constructionist communities are learning? What does it mean to be 'a constructionist'? How do we communicate this in a clear way to social and institutional structures? What scope can there be for a constructionist researcher in the next 10 years? I think these questions need to be asked.

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Mother's Day, Warrior Cats, and Digital Fluency: Stories from the Scratch Online Community

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Abstract

In many parts of the world today, young people grow up surrounded by computers, electronic toys, game machines, and mobile phones, and they use these digital devices to engage in a diverse range of activities: playing games, texting friends, exploring virtual worlds, searching for information online. But most young people have little experience designing and creating with digital media. They feel comfortable playing with interactive games, animations, and simulations, but not creating their own. They are not truly fluent with digital technologies: it is as if they can "read" but not "write." This paper uses stories from the Scratch online community to explore the meaning of digital fluency, providing examples of how young people can learn to express themselves fluently with digital media.

Keywords

Programming, fluency, Scratch

Story #1: Mother's Day

On Saturday, May 7, 2010, I suddenly realized that the following day was Mother's Day and I hadn't gotten a gift for my mom. So I started thinking about last-minute gifts. Instead of buying a gift, I decided that I would make my mom an interactive Mother's Day card, using the Scratch programming software developed by my research group at the MIT Media Lab.

Before starting to create my Mother's Day card, I decided to check out the Scratch community website, where people share Scratch projects. People have shared more than 2.5 million Scratch projects since we launched the website in 2007, so the website can serve as a great source of inspiration. By looking through the website, you can view and try out a wide diversity of different types of projects, many of which you never would have imagined on your own. I wondered if other people had created Scratch projects for Mother's Day, so I typed "Mother's Day" in the search box on the website, and pressed Return.

I was surprised and delighted by the results that appeared. There was a list of dozens and dozens of Mother's Day card, most of them created by young people between the ages of 8 and 16, the core demographic of the Scratch online community. I checked the dates on the projects, and I saw that most of them had been created in the past couple days, by procrastinators like myself.

I began clicking on the links to see the projects. One of the projects (see Figure 1) was a short animation featuring a kitten and a larger cat. The kitten turns around, sees the larger cat, and shouts out "MOMMIE!" Then, the kitten joyfully jumps on the big cat, knocks her over, and says "I ♥ U". At the end of the animation, the creator added a replay option, to make it easy for her mother to view the animation again (and again and again).

Figure 1: Sample Mother's Day projects from the Scratch community

Another project was an extended story in which a Scratcher explains how she had searched online to find the correct date for Mother's Day. The project includes photographs of her room and the computer on which she did the search, along with sound effects to simulate her keystrokes as she types the search query into the computer. The story ends with a cartoon image of herself saying "I love you SO much!" with arms stretching across the screen to show how much she loves her mom.

A third project started with the words "HAPPY MOM DAY" drawn on top of a large red heart. Each of the 11 letters was interactive, transforming to a word when touched by the mouse. As I moved the mouse across the screen, touching each letter, a special 11-word Mother's Day message was revealed: "I love you and care for you. Happy Mother's Day mom."

As I played with the Mother's Day projects, I felt a sense of satisfaction. This was exactly what our team at the Media Lab had hoped would happen when we developed Scratch. Our goal was to help young people become *fluent* with digital technologies. We hoped that young people would use Scratch to create projects that were meaningful in their everyday lives, not just as school assignments. We hoped that creating Scratch projects would become as common and familiar as writing an entry in your diary or baking a cake for a friend's party – or creating a card for your mom on Mother's Day.

Of course, most young people already spend lots of time interacting with digital media. They have grown up surrounded by computers, electronic toys, game machines, and mobile phones, and they use these digital devices to engage in a diverse range of activities: playing games, chatting with friends, exploring virtual worlds, searching for information online. Indeed, they are often described as "digital natives."

But, despite their comfort and familiarity with digital media, most young people have little experience *creating* with digital media. Even when they do create with digital media (for example, manipulating images with Photoshop or mixing music with Garage Band), they rarely create *interactive* projects, and thus do not take full advantage of the possibilities of digital media. Most young people feel comfortable playing with interactive games, animations, and simulations, but not creating their own. As I see it, they are not truly fluent with new digital technologies: it is as if they can "read" but not "write."

In developing Scratch, we wanted to support both reading and writing with interactive media. We wanted to enable everyone to create their own interactive stories, games, and animations – and to share their creations with one another. Our ideas were strongly influenced by earlier research on programming languages for young people, most notably the work on Logo and Squeak Etoys. We were inspired by this earlier work, but we also recognized the need to do some things differently. We designed Scratch to be:

- *More tinkerable*. To create programs in Scratch, you snap together graphical blocks into stacks, just like LEGO bricks, without any of the obscure syntax (square brackets, semi-colons, etc.) of traditional programming languages. Thus, it is easier to "tinker" with Scratch – quickly trying out new ideas, then continually modifying and refining.

- *More meaningful*. Scratch supports many different types of projects (games, stories, animations) and many different types of media (graphics, photos, sounds, music), so it can engage people with a wide diversity of interests, even people who had never imagined themselves as programmers.
- *More social*. The Scratch website hosts a vibrant online community with more than 1 million registered members. You can share and get feedback on your own projects, remix other people's projects, or join a "collab" to create collaborative projects.

If you look at the Scratch website, you get a sense of the fluency in the community. Young people (mostly ages 8 to 16) are using Scratch to create an extraordinary range of diverse projects, including interactive newsletters, science simulations, virtual tours, public-service announcements, re-creations of classic video games, animated dance contests, and even Mother's Day cards.

So what happened with my own Mother's Day card? As it turns out, I never ended up making a card for my mom. Instead, I sent her links to a dozen Mother's Day projects that I found on the Scratch website. And my mom, a lifelong educator, responded exactly as I hoped she would, sending me the following email message: "Mitch, enjoyed viewing all the kids' Scratch cards so much... and I love that I'm the mother of a son who helped give kids the tools to celebrate this way!!!!"

Story #2: Warrior Cats

A few years ago, I was invited to make a presentation at a conference called *Story 3.0*. The conference focused on "the innovation, culture, and business of next-generation storytelling," examining how digital technologies could transform the nature and role of stories in the 21st century, just as previous technologies (like the printing press and photography) had transformed story-telling in earlier eras.

I was scheduled to speak about story-telling in the Scratch community during the first morning of the conference. The speaker immediately before me was from an educational publishing company in Europe. His company was developing an immersive online world based on *Warriors*, the popular series of children's books that follow the adventures of four clans of wild cats in their forest homes. The publishing company hoped to leverage the popularity of the *Warriors* books to engage children in new forms of online interaction. As the speaker described in his presentation:

> *There will be hundreds of other cats in this forest with you... What will happen is that you will consume these narrative missions, and each mission is presented as an essential piece of the clan's mythology that you need to grasp.*

As I listened to this, one word jumped out at me: *consume*. From the point of view of the publishing company, digital technologies provided new ways for children consume stories. It was a stark contrast to Scratch, which provides opportunities for children not only to interact with other people's stories but to create and share their own.

As the publishing-company representative continued his presentation, I opened my laptop, went to the Scratch website, and typed "warrior cats" in the search box. A list with hundreds of projects and galleries appeared. Members of the Scratch community had been very active creating projects based on the *Warriors* books. One gallery called "BEST WARRIOR CATS PROJECTS!" had 150 projects. Another called "Warrior cat games and makers" had more than 70 projects (see Figure 2). "Warrior Cats Rule!" had more than 60.

Figure 2: Gallery of Warrior Cat projects on Scratch website

I started looking at some of the projects, hoping to integrate a few of them into my presentation. I opened a project called "Warriors cats maker 2," created by a Scratcher with username Emberclaw (see Figure 3). The project allows you to create your own Warrior cat. By pressing different buttons, you can select the length of the cat's fur (3 options), the color of the fur (16 options), the pattern of spots on the fur (11 options), the type of eyes (10 options), and the environment where the cat lives (4 options).

Next, I tried a project called "Warrior Cats Game v2," created by a Scratcher with username Flamespirit. In the game, you can use the arrow keys to move a cat through a series of environments, interacting (and fighting) with other cats along the way. You can press different keys to execute different fighting moves (such as Back Kick and Claw Attack), or click on plants in the environment to get information on their medicinal value.

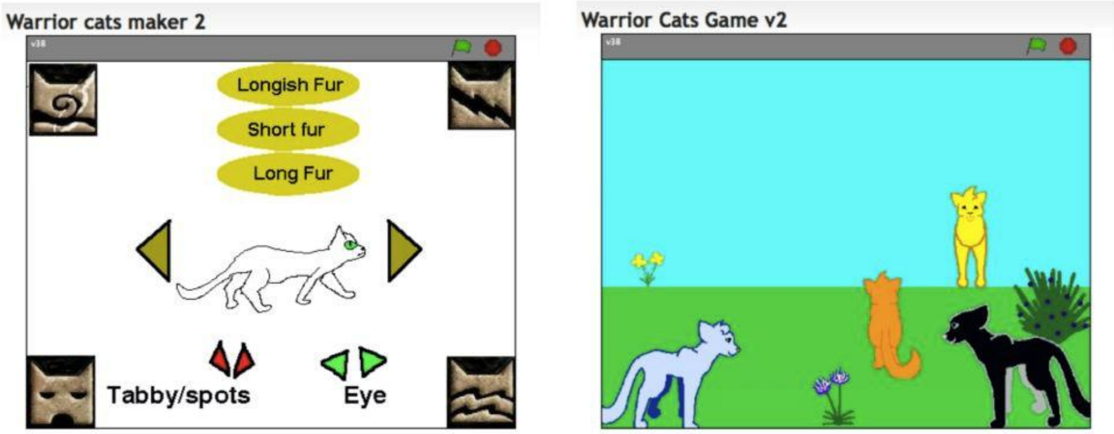

Figure 3: Sample Warrior Cat projects from the Scratch community

More than 1500 members of the Scratch community had played with the Warrior Cats Game v2 project, and they left more than 100 comments and suggestions. In response to a comment that said simply *Awesome!*, Flamespirit encouraged the commenter to try out a new, enhanced version of the project: *Posted v3. It has an extra level you'll love. Check it out!*

Another comment asked Flamespirit for advice:

> *OMG AWESOME! Hey, can you help me? I'm making a new-age interactive Warriors Cats game, a bit like yours, but with different styles... I just don't know how to interact! I know how to get the cats to jump, but to get onto different levels and to talk with others.... I'm stuck!*

Flamespirit responded:

> *To talk with others, I just programmed the cats to say something when clicked. As for the change of levels, I just programmed a key that would change backgrounds, and, if certain sprites touched certain colours, to just hide/show them.*

As I explored the Warrior cat projects on the Scratch website, I was still using half of my mind to listen to the Story 3.0 conference speaker talk about the new immersive online world based on Warrior cats. As the speaker was finishing his remarks, I quickly revised my presentation to include some of the Warrior cat projects from the Scratch community.

In my presentation, I emphasized the differences between the immersive online Warrior cats world (featured in the previous presentation) and the Scratch online community. For me, the two initiatives represent two very different approaches to story-telling with digital technologies – and, more broadly, very different approaches to education and learning. In both projects, children are actively participating and interacting with digital technologies, but the nature of the participation is very different. In the immersive online world from the publishing company, children participate by interacting with other characters and playing games. But, as described in the company's presentation, the children are "consuming" narratives, not creating their own. In the Scratch community, children both consume and create, trying out projects on the Scratch website but also creating and contributing their own narrative projects.

As I see it, participants in the immersive online Warrior cats world achieve a very limited form of digital fluency, learning to read but not write with digital media. Scratchers who create Warrior cat projects take steps towards a much fuller form of digital fluency, learning to use digital media to tell their stories and express their ideas to one another.

As they become more fluent with digital media, members of the Scratch community develop an important array of "fluency skills." In particular, they learn to:

- *Think creatively*. The ability to "create" is at the root of "creativity." As young people create characters and story lines for their Scratch projects, they are developing as creative thinkers, using their imaginations to explore new ideas and new directions.
- *Reason systematically*. In creating Scratch projects, young people must carefully and systematically combine programming blocks into scripts. Although we have tried to make Scratch as easy and intuitive as possible, programming in Scratch is not trivial: it still requires systematic reasoning.
- *Work collaboratively*. Members of the Scratch community learn to collaborate in many different ways. They give feedback through comments on projects, they work together on joint projects, they remix one another's projects, they crowd-source artwork for their projects, they create Scratch tutorials to share their knowledge with one another.

Of course, as young people work on Scratch projects, they also learn important mathematical and computational concepts, such as variables, conditionals, events, and parallelism. But, in my mind, the fluency skills of thinking creatively, reasoning systematically, and working collaboratively are far more important. These skills are essential for full participation and success in today's workplace, not only for computer programmers but for marketing managers, journalists, graphics designers, and most other occupations. And these skills are just as important for success and happiness in other aspects of one's life, from community participation to personal relationships.

Looking Ahead

In the five years since its launch, Scratch has emerged as the most popular way for children and teens to learn to program – and an important pathway for becoming fluent with digital media. But the current version of Scratch is just the beginning. We are continuing to refine and extend Scratch to engage broader and more diverse audiences, and to enhance opportunities for developing digital fluency.

Later this year, we will release a new generation of Scratch, called Scratch 2.0, which will move Scratch into the cloud, enabling people to program, save, share, and remix Scratch projects directly in the web browser. We hope that this new version will provide a more seamless experience for creating and collaborating with Scratch, since people will no longer need to download the programming application to their local machine, or upload their Scratch projects to the website. This new version will also enable Scratchers to:

- share at multiple levels of granularity, exchanging scripts, procedures, sprites, images, and sounds as well as projects
- store "persistent data" in the cloud to create online surveys, high-score lists, and interaction between projects
- create projects that react to movements and colors in the physical world by using the webcam as a sensor
- import sets of specialized programming blocks for continually adding new capabilities to the core language
- export projects from Scratch to other social-media sites

We are excited by these new features and capabilities. But we are also aware that the biggest challenges for Scratch are not technological but cultural and educational. Just developing a new generation of software is not enough. To help young people learn to express themselves fluently with Scratch, we need to develop new types of support materials, resources, and examples, for educators and for Scratchers themselves. Even more important (and more difficult), we need to encourage a cultural shift in the ways people think about computers and fluency, shifting people's conception of digital fluency to include the creation of interactive Mother's Day cards and Warrior cat games, not just the ability to interact with websites and online worlds.

Acknowledgements

My ideas about digital fluency have been inspired and influenced by the work of Seymour Papert (1980), Alan Kay (1991), Andy diSessa (2000), and Henry Jenkins (2006). Many members of the Lifelong Kindergarten research group at the MIT Media Lab contributed to the ideas and technologies discussed in this paper. To learn more about Scratch and the educational ideas underlying Scratch, see the Scratch website (http://scratch.mit.edu), the ScratchEd website (http://scratched.media.mit.edu), and the Scratch Team's overview article about Scratch (Resnick et al., 2009).

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Constructionism and the new learning analytics

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Introduction

Once upon a time, constructionism was fresh and new. In those early days, the world of education was a very different place. We needed to more than just sell educators on the constructionist vision; we needed to convince them that computers would one day be inexpensive enough, and ubiquitous enough, to be part of the everyday infrastructure of schools.

Today, it has been over three decades since Mindstorms was first published (Papert, 1980). The vision laid out there has proven to be remarkably resilient. Even now, the examples presented in Mindstorms evoke strong reactions, and they remind us of what education *could* be. But the world around us has been changing dramatically. It used to be a special day when a student had the opportunity to sit down in front of a computer. Now, it is increasingly the case that computers are seen as part of the basic infrastructure of learning.

This means that, although the constructionist vision might be largely unchanged, the larger world is different. The battles we have to fight are very different than those we fought only a short time go. It might also mean that there are new things we can learn, and that the constructionist vision can be updated.

In this paper, I focus my attention on one important trend in the world of educational technology: the increasing use of *computational methods* of various sorts in educational research. There are two forces driving this trend. One force is the increasing amount of student work that is done on computers. When student works on computers—especially when they work online—they leave what has been called a "data exhaust:" a trail of mouse clicks, forum posts, and e-mail that is relatively easy and inexpensive to capture (e.g., Buckingham Shum & Deakin Crick, 2012). Although there is certainly much student activity that is not captured in this data exhaust, the sheer volume of data that can be captured in this manner is astonishing; it dwarfs, by orders of magnitude, the data about learning that can be captured in any other way.

Of course, analyzing these vast sets of data poses significant challenges. But here we are helped by a second force that is driving this trend toward computational methods. Researchers (such as you and I) have increasingly powerful computers at our disposal—computers with vast storage and fast processing speed. Although analysis of these vast data sets can still be challenging, the tools that we now have at our disposal give us abilities that would have been unthinkable less than a decade ago.

We can localize much of the use of computational methods in education within two communities. One is the *educational data mining* (EDM) community; the other the *learning analytics* (LA) community. In order to understand trends in the use of computational methods, it is worth taking some time to tease apart EDM and LA. The EDM community is older, and seems to have largely been built upon the intelligent tutor community, a community that has been around for nearly as long as constructionism. This makes great sense; researchers in intelligent tutors have been capturing (and analyzing) mouse clicks and other student data since the earliest days in the field. Research in the educational data mining literature seems to be largely focused on developing sophisticated algorithms that serve as "detectors" of interesting features of student activity, such as attempts to "game" the system or moments of real learning (e.g., Baker, Corbett, Roll, & Koedinger, 2008). The prototypical image that comes out of this community is one of a student interacting with a smart system that has a constantly updating model of everything that the student knows, and that can adapt its responses based on this model and other detectors of student activity.

The *learning analytics* community is somewhat newer, and it seems to have been spawned by the more recent ubiquity of online work by students, particularly at the undergraduate level (Long & Siemens, 2011). Here the prototype image is one of an undergraduate student who makes use of an online course management system, such as Blackboard, or who interacts with a full-blown online course. Here there is less emphasis on sophisticated algorithms or on building intelligence into the systems. Instead, the emphasis is on compiling the data and presenting it to people for use and interpretation. The data can be presented, for example, to instructors, student advisors, or the students themselves. Part of the idea is that the use of this data can lead to more efficient and effective instruction, and fewer students who "fall through the cracks." If, for example, an instructor or advisor is notified that a student has been only rarely logging on to complete assignments or post to forums, they can intervene so as to get the student back on track.

What does the rising importance of these computationally-based methods mean for the constructionist mission? Are educational data mining and learning analytics consistent with constructionist philosophy? I believe that these new analytic methods provide us with tools that can be used for good, but also hold the possibility of being used for evil (or, at least, in ways that run counter to the constructionist vision). I believe that, as these computational methods are currently employed, they will tend to lock in the status quo. In both EDM and LA, the instructional image is one in which all students are rigidly guided along the same path. In the prototypical application of EDM, students are studied as they interact with an intelligent system that has a model of the ideal understanding that is to be engendered, in the form of a cognitive model of this ideal understanding. In LA, the prototypical image is one of an instructor herding a large group of students. The information provided by learning analytics helps them to make sure that there are no strays, and that all students are efficiently guided to the same destination.

Clearly, neither of these prototypical images is a good fit with constructionism. Constructionist tools are intended to be protean; they are designed to allow students to engage in intellectual work that is, at least to some extent, driven by personal interests and questions. Thus, if LA and DM perpetuate an image in which large numbers of students are guided along the same rails, toward the same end goal, then they will be forces that are anti-constructionist. Just the feeling that someone is watching could, on its own, stifle students' inclinations to explore.

However, I believe that there are ways that techniques from EDM and LA can be harnessed to advance the constructionist mission. In fact, if these techniques are used productively, they can be more congenial to the constructionist stance than traditional statistical methods of examining learning. There are even some reasons to believe constructionists can be influential, and that we can turn the tide in how these new methods are being used. These new methods are *computational* methods. Experts in these methods are computer scientists, not statisticians. That helps us, because many of us are programmers.

Data: The seasons Corpus

To illustrate what is possible, I am going to draw on some of my own work. My purpose here is to provide readers with a sense for some computational tools and techniques that can form the basis of a type of learning analytics that is congenial to constructionism.

To do this, I will draw on my analysis of a set of 54 clinical interviews in which middle school students were asked to explain the seasons. The data that I analyze computationally consists of transcripts form these interviews. This might seem to be a strange place to start; I am not going to be analyzing data that was produced by students working in a constructionist mode, building artifacts. Nonetheless, I believe this is the right place for me to begin. One reason is pragmatic: this is one of my computational analyses that is most developed. But there is a second reason that is more fundamental; I believe that we will frequently want to look beyond the "data exhaust" that is produced as students interact with a computer. In some cases, we will want to make use of an enriched dataset that combines the data exhaust with speech and textual data. A focus on speech also opens up the possibility of learning analytic methods to data that is produced when students engage in constructionist activities that don't involve computers.

Although I am not looking at a constructionist learning activity, my stance toward the data is, I believe, compatible with the constructionist stance. In my earlier analyses of this data, I argued that the students interviewed constructed explanations of the seasons by fitting together a set of relative basic elements of knowledge (Sherin, Krakowski, & Lee, 2012). These elements included, for example, the knowledge that the sun is very hot, and that a heat source is felt more strongly closer to the source. The elements also included knowledge about the motion of the earth, including the fact that it orbits the sun in an ellipse, rotates, and is tilted relative to its plane of motion.

Out of these cognitive elements, the students were able to construct a wide range of explanations. For example, students sometimes gave what we call *closer-farther* explanations. In these explanations the Earth moves such that it is sometimes closer and sometimes farther from the sun. When it is closer to the sun, it experiences summer; when it is farther, it experiences winter. At other times, students gave *side-based* explanations. In these explanations, the Earth's rotation causes one side and then the other to face the sun. The side facing the sun experiences summer. Students also sometimes gave what we call tilt-based explanations in which the tilt of the Earth causes one hemisphere or the other to be tilted toward the sun. The hemisphere tilted toward the sun experiences summer. (The correct explanation is an elaborated tilt-based explanation.)

Here I will briefly give examples from a few interviews. The first example is taken from an interview with a student we call Edgar. In this example, Edgar begins by giving a side-based explanation, in which the side facing the sun experiences summer because the rays strike more directly there. His diagram is shown in Figure 1.

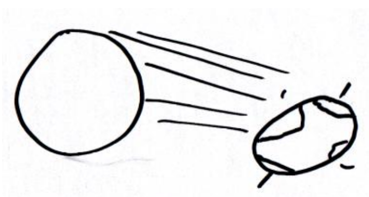

Figure 1. Edgar's drawing.

> E: Here's the earth slanted. Here's the axis. Here's the North Pole, South Pole, and here's our country. And the sun's right here [draws the circle on the left], and the rays hitting like directly right here. So everything's getting hotter over the summer and once this thing turns, the country will be here and the sun can't reach as much. It's not as hot as the winter.

However, when Edgar was asked about the motion of the earth, he immediately shifted to giving a closer-farther type explanation:

I Let's say we're here and it's summer, where is it, where will the earth be when it's winter?

E Actually, I don't think this moves [indicates earth on drawing] it turns and it moves like that [gestures with a pencil to show an orbiting and spinning earth] and it turns and that thing like is um further away once it orbit around the s- earth- I mean the sun.

I It's further away?

E Yeah, and somehow like that going further off and I think sun rays wouldn't reach as much to the earth.

Thus, in a short space of time, Edgar assembled a few basic knowledge elements into two different explanations of the seasons. I want to briefly give two additional examples in which students gave varieties of tilt-based explanations. In the first example, Caden says that the hemisphere tilted toward the sun is warmer because it is closer to the sun.

I: So the first question is why is it warmer in the summer and colder in the winter?

C: Because at certain points of the earth's rotation, orbit around the sun, the axis is pointing at an angle, so that sometimes, most times, sometimes on the northern half of the hemisphere is closer to the sun than the southern hemisphere, which, change- changes the temperatures. And then, as, as it's pointing here, the northern hemisphere it goes away, is further away from the sun and get's colder.

I: Okay, so how does it, sometimes the northern hemisphere is, is toward the sun and sometimes it's away?

C: Yes because the at—I'm sorry, the earth is tilted on its axis.

I: Uh uh.

C: And it's always pointed towards one position

Like Caden, Zelda gave a tilt-based explanation. But, in her explanation the hemisphere tilted toward the sun is warmer because the "sun shines more directly on that area."

I: Why do you think, what is, could you tell me your best guess, why its warmer in the summer and colder in the winter?

Z: Because, I think because the earth is on a tilt, and then, like that side of the earth is tilting toward the sun, or it's facing the sun or something so the sun shines more directly on that area, so its warmer.

I: Can you draw a picture? It doesn't have to be artistic or anything.

Z: So that was the sun, and like the earth, if this is the top its like tilted so the sun shines on like the bottom part, its tilted back.

Vector space analysis of the seasons corpus

Transcripts of interviews, such as those presented in the preceding section, constitute the data that we want to analyze computationally. One way we could imagine analyzing this data could be in terms of families of explanations, such as "side-based" and "tilt-based." But we would prefer an analysis that is sensitive to the fact that each explanation might be a somewhat personal instruction; we want an analysis that can (1) looking across all students, identify the set of building blocks out of which students construct explanations of the seasons, and (2) for each student, produce an analysis of how that student constructed an explanation out of these building blocks.

It might seem to be very difficult to perform an automated analysis of transcript data that can accomplish these two steps. But it turns out that there are relatively simple methods we can borrow from computational linguistics that can do this work. The methods are simple enough, conceptually speaking, that I can fully explain them here. They are also simple to apply, in practice, because there are open source routines that we can use when building our software tools.

In my work, I have made use, in particular, of a set of open source Python routines called the Natural Language Toolkit (Bird, Klein, & Loper, 2009). Using these routines, relatively complex analyses can be produced with only a few lines of additional programming.

Mapping texts to vectors

The methods I will describe are based on a family of methods from computational linguistics known as *vector space models*. There are many types of vector space models, here I use a very simple type. In vector space models, every passage of text is mapped onto a vector, and two passages are understood to have the same meaning if their vectors point in the same direction. More precisely, the similarity in meaning is measured by the dot product between the two vectors. If the dot product is high, then the two passages have similar meanings. If the dot product is small, the meaning is different. As we will see, this ability to measure the similarity in meaning between two passages can afford us a great deal of analytic power.

The trick, of course, is that we need a way to map a passage of text onto a vector of the right sort. Here I do that in a relatively simple way. First, we construct a vocabulary by combining all of the words that appear in the full set of transcripts that we wish to analyze. Python has powerful abilities for working with *sets* that allow us to do that in just a few lines. If seasons_corpus is a Python *dictionary*, indexed by student name, and each entry contains the text of the interview, then we can compile the vocabulary by writing:

```
set_vocab = set([])
for name in student_names:
   set_vocab = set_vocab.union(set(seasons_corpus[name]))
```

Once the full vocabulary is built, we usually remove a set of "non-content" words—highly common words such as "the" and "or" that are not helpful for distinguishing the content of a passage. This list of words to exclude is usually called the "stop list."

```
set_vocab = set_vocab.difference(stop_list)
```

For the analysis I'll report here, the full vocabulary contained 1429 words, the stop list contained 782 words, and the reduced vocabulary contained 647 words.

Once we have the reduced vocabulary, we can compute the vector for a passage of text. To do this, we loop through the entire vocabulary, computing how many times each word appears in the passage. (To do this in Python, the vocabulary has to first be converted from a *set* to a *list*.) The result of this looping process is a list of numbers corresponding to the words in the vocabulary. In Python, this can be done in a single line:

```
passage_vector = [passage_text.count(word) for word in vocab_list]]
```

This passage vector is usually transformed in two ways prior to proceeding farther with the analysis. First, the counts are weighted in some manner. In my analysis, I replaced each of the counts that appear in the corpus with 1+log(count). This has the effect of diminishing the effect of large counts. (Counts of zero are left unchanged.) Second, the entire passage vector is normalized so it has a length of one.

Clustering vectors to discover building blocks

We can now use this method of mapping texts to vectors to discover the "building blocks" in student explanations. To begin, I prepare each of the transcripts, by removing everything except the words spoken by the student. Then I take each of the transcripts and break it into overlapping 100-word segments. These segments are produced by a moving window that steps forward 25 words at a time. So the first segment has words 1-100, the second segment has words 26-125, etc. When this is done to all of the 54 transcripts, I end up with a total of 794 segments of text. Each of these segments is then mapped onto a vector, using precisely the method described in the preceding section.

```
for name in student_names:
  passage_vectors[name] = [seasons_corpus[name].count(word) for word in vocab_list]]
```

The next step is to cluster the vectors. Recall that the direction a vector points is understood to represent the meaning of the corresponding passage. Thus, we want to find sets of passages with vectors that point in roughly the same direction. These sets will correspond to our "building blocks."

To find these clusters, we can use any of many clustering techniques. Here I will report results that were derived from Hierarchical Agglomerative Clustering (HAC). In HAC, we begin with each of the vectors to be clustered in its own cluster. Then we iterate and, on each iteration, we merge the two clusters that are the most similar. To determine similarity, we first find the centroid vector for each cluster (the average of all of the vectors that combine the cluster). Then we find the pair of clusters that has the largest dot product, and we merge them.

Table 1. Number of segments in each cluster for various cluster numbers.

# of clusters	Sizes of the clusters
10	19 72 9 68 140 62 44 122 136 122
9	19 72 68 62 44 122 136 122 149
8	19 72 68 44 122 136 122 211
7	72 68 44 122 122 211 155
6	68 44 122 122 211 227
5	68 122 122 211 271
4	122 122 271 279
3	271 279 244

In this way, HAC produces a sequence of candidate clusterings of the data. This sequence begins with each of the vectors in its own cluster and it ends with all of the vectors in one large cluster. Table 1 shows the results from near the end of the process, when there are between 10 and 3 clusters. In each row of the table, I have included the sizes of the clusters. So, for example, when the vectors are grouped into three clusters, these clusters contain 271, 279, and 244 vectors respectively. Because NLTK contains classes that handle clustering, all of this can be handled with just a few of lines of programming, one that creates an instance of a clustering class, and another that uses it to cluster the set of vectors.

```
clusterer = ClustererClass()
clusterer.cluster(list_of_vectors)
```
[1]

The final step in clustering the vectors is to decide which of the candidate clusterings to select. This must be done heuristically. In practice, I have found that working with about 7 clusters strikes a nice balance; it captures importance nuance in the data without too much complexity.

[1] This discussion of clustering skips over one subtlety. In order to get meaningful results, I need to process the vectors in one additional way prior to clustering them. I first compute what I call *deviation vectors.* To do this, I compute the average of the full set of 794 vectors. Then I subtract this average from each of the vectors. The result is that each vector is replaced by a vector that corresponds to its difference from the average.

The meanings of the clusters

Each of the 7 clusters produced by the preceding analysis is supposed to correspond to one of the building blocks of meaning out of which students construct explanations of the seasons. We now need a way of figuring out the *meaning* of these clusters. To do this, we compute the centroid vector of each cluster. This centroid is a list of numbers, with each number corresponding to one of the words in our vocabulary. This suggests a way to understand the meaning of each cluster: we can take the values in each centroid vector that are the highest, and then list the corresponding words. In Figure 2, I have done that for each of the 7 clusters. In particular, I list the 10 words that have the highest value in each centroid vector. The third column in each table gives the overall frequency of the word in the corpus.

Cluster 1		
tilted	0.767	82
towards	0.199	40
away	0.186	83
north	0.098	30
part	0.084	46
guess	0.077	31
closer	0.044	82
warmer	0.042	40
sun	0.03	545
farther	0.017	71

Cluster 2		
earth	0.4	395
spinning	0.366	37
spins	0.2	38
time	0.198	65
axis	0.121	77
seasons	0.068	30
tilted	0.031	82
angle	0.017	31
north	0.014	30
chicago	0.006	45

Cluster 3		
hemisphere	0.603	47
northern	0.522	31
colder	0.119	52
facing	0.106	46
closer	0.043	82
farther	0.035	71
warmer	0.023	40
axis	0.021	77
away	0.02	83
rays	0.018	33

Cluster 4		
side	0.722	95
facing	0.091	46
earth	0.085	395
part	0.068	46
chicago	0.018	45
guess	0.008	31
seasons	-0.008	30
time	-0.01	65
heat	-0.025	30
rotates	-0.026	54

Cluster 5		
rays	0.293	33
north	0.197	30
angle	0.194	31
light	0.188	41
chicago	0.163	45
sun	0.134	545
heat	0.076	30
towards	0.045	40
warmer	0.02	40
side	0.019	95

Cluster 6		
day	0.415	75
moon	0.398	52
night	0.377	63
rotates	0.178	54
rotating	0.068	32
earth	0.055	395
spins	0.05	38
facing	0.048	46
light	0.046	41
seasons	0.046	30

Cluster 7		
farther	0.413	71
closer	0.403	82
away	0.379	83
colder	0.216	52
sun	0.103	545
warmer	0.064	40
rotates	0.033	54
time	0.028	65
heat	0.02	30
rotating	0.013	32

Figure 2. Words and their corresponding values in the centroid vectors.

I believe that the lists of words shown in Figure 2 are suggestive of clear meanings. For example, Cluster 1 seems to be about the tilt of the earth, while Cluster 7 is about something being closer or farther from a heat source (usually the sun).

Applying the cluster vectors to the transcripts

Once we have these "building blocks" we can use them to analyze each of the 54 transcripts. To do this, I first take each transcript, segment it as before, and compute vectors for each of these segments. Then I compare these vectors for segments to the vectors that correspond to each of the 7 cluster centroids.

When this is done for Edgar's transcript, the results are as shown in Figure 3. In this analysis, the transcript has been broken into 10 segments. For each of these 10 segments, there are 7 bars, corresponding to the 7 cluster centroids. In the first part of the transcript, the bar corresponding to Cluster 5—the blue bar—dominates. This cluster has to do with rays striking the earth's surface. Cluster 7 dominates in the latter half of the transcript. This is the cluster that has to do with being closer or farther from a source. Furthermore, this shift occurs at around the right time in the transcript.

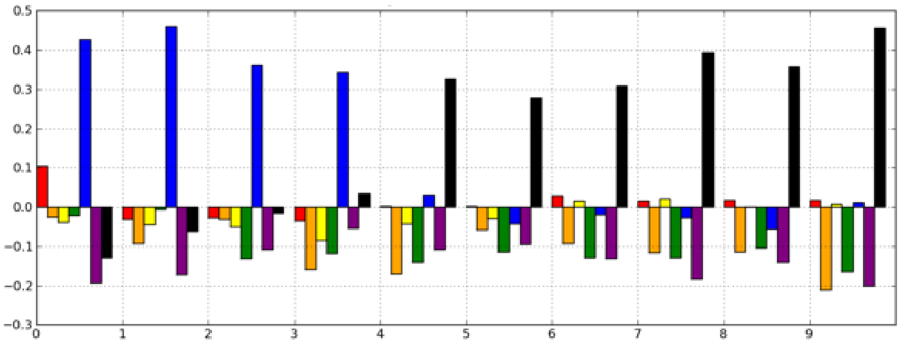

Figure 3. Segmenting analysis for Edgar.

The analysis for Zelda is a bit simpler. Cluster 1 dominates throughout the entire transcript. This is the cluster that has to do with the earth's tilt. This makes sense since Zelda's explanation was tilt-based. It is also important to note that the blue bar—Cluster 5—is comparatively high in some of the segments. This is the bar that has to do with rays striking the earth at an angle.

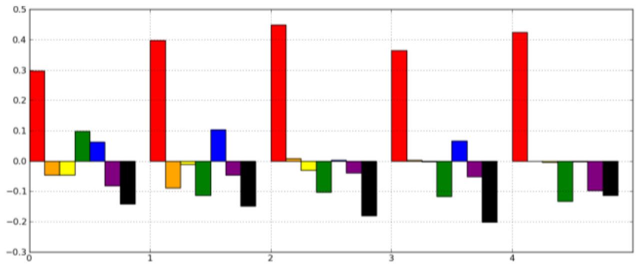

Figure 4. Segmenting analysis of Zelda's transcript.

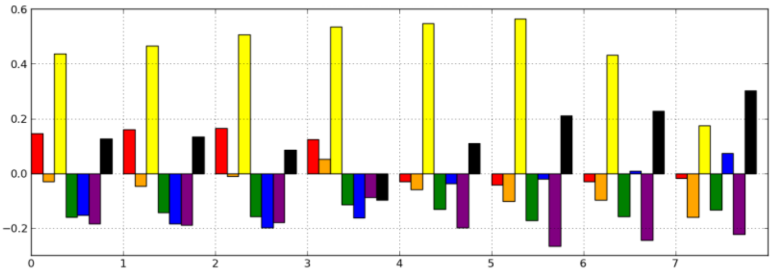

Figure 5. Segmenting analysis of Caden's transcript.

The analysis for Caden makes an interesting contrast to the analysis for Zelda. We understood Caden as also giving a tilt-based analysis. As can be seen in Figure 5, Cluster 3 dominates in many of the segments. This has to do with the earth's hemispheres. But Cluster 1 (tilt) and Cluster 7 (close and farther) also appear. This makes sense since Caden gave an explanation in which first one hemisphere, then the other, is tilted toward the earth. And unlike Zelda, Caden said that this tilting affects the earth's temperature because one hemisphere will be closer to the sun (not because it received more directly sunlight). Thus, this analysis captures relatively subtle differences between these two tilt-based explanations.

Conclusion

I hope that the preceding analysis makes it clear that there are simple yet powerful computational methods that can capture the richness and diversity of student reasoning. They are conceptually simple—the algorithms involved can be described in just a few words, and they don't rely on sophisticated mathematics. The algorithms are also easy to apply in a very practical sense, since there is publically available source code that can be drawn upon (as long as we are willing to work in Python). There is still some programming to be done. But all that is required is a few lines of programming to link together the publicly available code.

The analysis I presented here is a type of learning analytics. But hopefully it is clear that the methods I described can be used for more then determining if students are being efficiently channeled toward a desired end goal. They can be used to find commonalities across students (in the form of the building blocks), and they also allow us to capture more personal aspects of students explanatory constructions.

I worked with transcript data here. As I said earlier, I believe that the data employed in EDM and LA should ultimately incorporate more use of richer kinds of data, including spoken language and text.

I have only scratched the surface here of the types of methods that are available to us. I presented just one type of vector space model; there are many more sophisticated alternatives. And, within computational linguistics and machine learning, vector space models and clustering are just two examples drawn from a wide range of methods, many of which could be applied for similar purposes. (See, for example, Manning & Schütze, 1999.) I hope that in presenting just a single example analysis I have convinced the reader that it is possible to use computational methods to analyze data in a way that is consistent with the constructivist vision. It can be a force for good rather than evil.

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Panel Debates: Rationale

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In the first Constructionism conference in Paris we found the climate to be relatively reflective and introvert. In this conference Wally Feurzeig, Richard Noss ,Jim Clayson, Ivan Kalas and I felt that it would be important to discuss ways in which Constructionism can avoid becoming a victim of fragmentation, self-referencing and loss of relevance to what's going on in research and education worldwide. We would therefore like to give a push to re-addressing Constructionism in a pluralistic world, to go beyond its reference to mathematics and computer science education, to make identifications, ask questions and forge connections with trends, theories, technologies and mindsets in society and educational systems. We feel strongly that constructionist epistemology and associated technologies and learning and design theories have a lot to give yet and need a lot more work on how they can be reified into practices. The 2012 Conference included the following four panel debates, each with a 'burning theme' for the Constructionist community.

- **Panel Debate 1**: Changing the subject
- **Panel Debate 2**: Segregation forever?
- **Panel Debate 3**: How do we know it when we see it?
- **Panel Debate 4**: Constructionism and Policy

Panel - debate 1: Changing the subject

Leader*: Michelle Wilkerson-Jerde*

Constructionism is often thought of as essentially a theory of instruction. There is truth to this, especially in its relation to traditional instructional strategies. But in fact, as Papert pointed out, it is much more than this. It is a theory of epistemology. It recognises that the computer presence can fundamentally alter the relationships between knowledge elements, how a subject domain is constructed, not only how it is conceived. Here is where the idea of 'restructuration' originates – how might a domain of knowledge be re-visioned to enhance its learnability – to make unlearnable ideas learnable by radically transforming how they are expressed. Hard ideas are sometimes hard because of the way we represent them: changing the representational infrastructure changes not only how 'easy' it is to learn an idea, but the idea itself. Key questions for this panel include:

- How can resistance to changes in current knowledge domains and curricula be challenged?
- What kinds of representations and what kinds of actions on them may catalyze the generation of meanings?
- How do we assess conceptual development in constructionist scenarios?
- What kinds of subjects are learnable given suitably-designed technologies and cultures?
- What kinds of subjects are learnable given suitably-designed technologies and cultures?
- The time for providing impressive examples is passing. We now need structure, comprehensive propositions and longitudinal data from learners. How can we intervene to make such changes happen?

Panel - debate 2: Segregation for ever?

Leader*: Paulo Blikstein*

Is constructionism in danger of becoming a victim of fragmentation, self-referencing and loss of relevance to what's going on in research and education wordlwide? Do we feel it is worth trying to position constructionism in a pluralistic world, to go beyond its reference to mathematics and computer science education, to make identifications, ask questions and forge connections with trends, theories, technologies and mindsets in society and educational systems? Do we need to forge a niche for constructionist epistemology and associated learning and design theories in amongst a pluralism of theoretical frameworks and constructs? There are more than one communities in Europe and world-wide searching for ways to integrate approaches and theories in design, learning and teaching, so that each one is more identifiable and at the same time plays a part in the extent and the ways in which our growing knowledge can be put to use in educational practices around the world. Do we feel the constructionist community should be in on this effort? How can we contribute? What are the connections and differences between constructionism and e.g. inquiry learning, collaborative learning, learning in collectives and classroom contexts? This panel will begin a debate on the value of creating such connections and the ways in which such a venture could progress

Panel - debate 3: How do we know it when we see it?

Leader*: Paul Goldenberg*

Those of you who attended Constructionism 2010 in Paris did hear, on many occasions in the plenary sessions, someone shout out "but that's NOT constructionism". This would be followed, with equal passion, by the opposite view. But we never developed those shouts into a conversation. It's not enough simply to say that we are 'anti-instructionists'. In the world we live in, we need to re-address how we can describe and demonstrate constructionism amongst our community and to others. We need to develop words and methods to convince others of its value, its nature and its sustainability in life-long learning. Most teachers, parents, students, decision makers don't have any idea of what constructionism is and confuse it with all manner of approaches. We have never really opened up conversations with our potential colleagues especially outside math and science. No wonder we are often portrayed as a peripheral group. This panel will be an exercise in describing experiences of 'the real thing', the real essence of constructionism from some concrete example. The descriptions will address both the constructionist community and external stakeholders. The panel leader will encourage others to comment and state their agreement or disagreement. The session will be recorded so comments can be distributed to others for their comments.

Panel - debate 4: Constructionism and Policy

Leader: *Jose Valente*

At the present time when there are universal moves for cost-cutting in education along with more accountability in schools for student performance as measured against performance in standardised tasks often in automated-digitized forms. In this context is constructionism in danger of fragmentation and marginalisation, and if so what are the moves that be undertaken to combat these tendencies?

While there is no identifiable specific articulated agenda against constructionism (or any pedagogical stance, theory or method) the value of pedagogy being put into practice is questioned as a whole. What are the evidence-based arguments that can and should be articulated in favour of a constructionist approach to teaching and learning that is aligned to a richer view of the meaning of education for all?

How can the constructionist community best produce such evidence, not only in small scale design experiments but at scale and what might be the means by which this evidence is disseminated?

A Turtle's genetic path to Object Oriented Programming

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Abstract
The good old idea of Turtle graphics still has an enormous potential. This paper presents an approach which uses three-dimensional Turtle graphics as a pathway to object oriented programming.

Keywords
Turtle Geometry, 3D, Programming, Object Oriented Programming, Python

Introduction

The turtle introduced by Seymour Papert may be considered to be the most important prototype of an artificial and abstract (depending on its incarnation) object that students interact with. By now it has a rich history with many variations of the approach (e.g.Papert, 1993, Abelson & DiSessa, 1981, Hromkovič, 2010). While originally introduced with the Logo programming language, the idea has migrated to many other languages and environments influencing many microworlds designed for the learning of algorithmic programming concepts (e.g. Scratch, NetLogo, Kara). Turtle geometry has also been used successfully in mathematics (Heid & Blume, 2008).

This paper presents an approach that combines two logically independent yet didactically useful extensions to the original concept: 3D and object orientation.

There are several projects that extend the Turtle into the third dimension (Paysan, 1999, Wolfram Demonstrations Project, "Elica,", "NetLogo 3D,"). Our approach to computer science introduction in high school is based on the conviction, that a mainstream language should be used that spans the whole learning time in high school to give students the opportunity to acquire a solid understanding of the language's semantics so that they can use it to express algorithmic ideas. In our case we decided to use Python. For Python there exists the very nice extension package "Visual Python" (short: VPython, www.vpython.org) to do easy 3D graphics, but there has no turtle been implemented for it yet. Thus we did this ourselves and built the package VTools that includes the class Turtle3D accompanied by some other helper functions for 3D Programming. The advantage of having a turtle in a mainstream language over using specialized environments is that other concepts of computer science can be linked. E.g. the turtles in Netlogo are nice and useful in many ways but there is no way to do standard (object oriented) programming with them.

Object orientation is quite natural with turtles. The build-in 2D turtle that ships with each Python distribution (as well as many turtle extensions for Delphi, Java etc.) is defined as a class so that one can create more than one turtle and this is a good starting point to introduce the dot notation widely used in OO languages: If you have two turtles, `turtle1` and `turtle2`, you must specify to which turtle a command is addressed to and students grasp the meaning of `turtle1.forward(5)` at once. This should help as well against the sometimes observed misconception that students don't distinguish between class and objects.

Turtle graphics are used in some courses that aim at object oriented programming (OOP). In (Schaub, 2000) it is used as an introduction to programming but it is not continued when the concepts of OO are introduced. Thus it seems that there is a lack of literature connecting turtle graphics and more advanced OO programming concepts.

In this paper we first provide an overview of the 3D turtle, its possibilities and its use in introducing algorithmic concepts (which is quite standard) and consider OO in the following section.

The Turtle3D and its use in algorithmic programming

In the course of our school pilot project "genetic computer science education" (cf. Schuster, 2011) we have been looking for a suitable environment for the introduction of algorithmics, that should open the scope for object oriented programming or at least does not block it. Classical turtle graphics could have been an option, but in our opinion the resulting pictures are not very motivating for high school students. As they are familiar with 3D representations in computer programs (games, …) it seemed obvious to use this as connection factor. Thus we developed a Python module (a library) that allows controlling a turtle in 3D space.

Features of the 3D turtle

The following code imports the library, creates a 3D turtle and executes some of its methods. The program paints a dashed line and a square. It can be executed interactively on the Python console or from a file.

```
from VTools import *
t=Turtle3D() # Creates a Turtle, with green pen color by default
t.forward(1)
t.penUp()
t.forward(1)
t.penDown()
t.forward(1)
t.turnRight(90)

t.setColor(color.blue)
for i in range(4):
    t.turnUp(90)
    t.forward(3)
t.forward(2)
```

This is the resulting image:

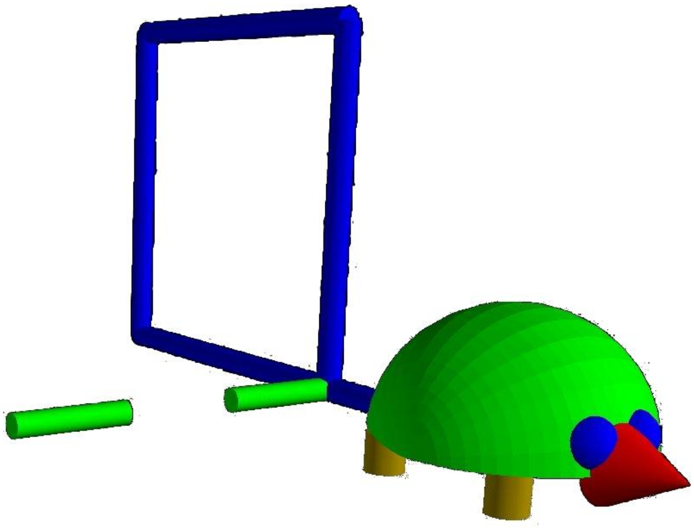


Figure 1. The turtle and a trace left by it

Only very few commands are needed to control the turtle. All turtle commands are methods that have to be applied to a Turtle3D object.

method	**action: the turtle …**	**example**
`forward(a)`	moves `a` steps forward.	`t.forward(5)`
`backward(a)`	moves `a` steps backwards.	`t.backward(5)`
`turnLeft(w)`	turns left by the denoted angle `w`.	`t.turnLeft(45)`
`turnRight(w)`	turns right by the denoted angle `w`.	`t.turnRight(45)`
`turnUp(w)` `turnDown(w)`	turns up / down by the denoted angle `w`.	`t.turnUp(45)`

`penUp()`
`penDown()`
	toggles its pen's status. The given example paints a dashed line.	`t.forward(30)`
		`t.penUp()`
		`t.forward(30)`
		`t.penDown()`
		`t.forward(30)`

`setVisible(b)`	If b is true, the turtle is visible.	`t.setVisible(False)`
`setAnimated(b)`	If b is true, the turtle moves slowly animated. If b is false, the resulting painting appears instantly.	`t.setAnimated(False)`
`setColor(col)`	Sets the color of the turtle, e.g. color.red, color.blue or	`t.setColor(color.yellow)` `t.setColor((1,0,0))`

	as rgb-values consisting of numbers ranging from 0 to 1.	`t.setColor((0.5,0.2,0))`
`setThickness(c)`	Sets the thickness of the line to c. The default thickness is 0.1.	`t.setThickness(0.5)`
`goto((x,y,z))`	moves to (x,y,z).	`t.goto((1,5,-3.2))`
`lookdir(v)`	looks into the direction of the given vector v.	`t.lookdir((0,1,0))`

Algorithmics with the 3D turtle

After the students have learnt the basic functionality, they can paint freely and express their creativity. Doing so, they can build several complex graphical objects with the turtle. The generated code may probably consist of many repeating blocks like the following but much longer (as we experienced in our teaching experiment, within one hour students can produce hundreds of lines):

```
t.forward(10)
t.turnRight(90)
t.forward(10)
t.turnRight(90)
t.forward(10)
t.turnRight(90)
```

While students are writing these kinds of repetitions (mainly by copying program text), they ask themselves if there is a way to automatically repeat the commands. This question emerges straight out of the student's experience and leads a genetic way to the loop-concept that answers this question.

The elementary concept of reference through variables can be introduced quite naturally as well: The students' wish to alter the dimensions of certain parts of the drawing (e.g. the side length of a cube) leads to the time-consuming and error-prone search in the code for places to change this length. It is better to previously specify variables to define them. By doing so the drawing is parameterised by the reference to the given value and can easily be repeated with other values.

Now, that students realize that certain operations (e.g. the drawing of a rectangle) reoccur again and again, the wish for procedural abstraction arises.

```
def rectangle(a,b):
    for i in range(2):
        t.forward(a)
        t.turnDown(90)
        t.forward(b)
        t.turnDown(90)
```

Other examples for reusable forms are regular polygons, circles, stars and so on. In the following example, rectangles are used to draw a cylinder.

```
def cylinder(radius,height,n=150):
    for i   in range(n):
```

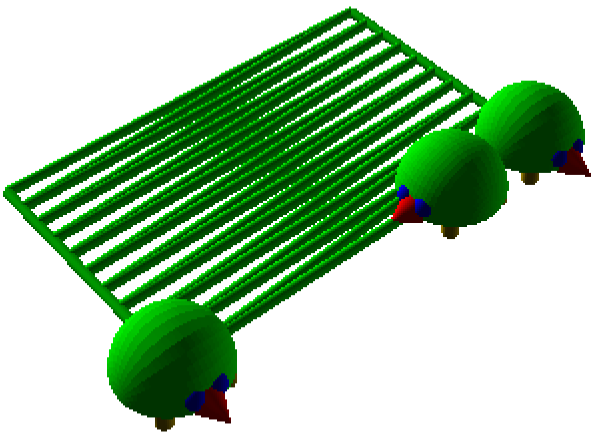
```
        t.backward(radius)
        rectangle(2*radius,height)
        t.forward(radius)
        t.turnLeft(360.0/n)
```

Definitions like these demonstrate an important role of functions: they are constructors (in a sense close to the meaning of constructor in object-oriented programming). They only differ from inherent constructors like Turtle3D() by the fact that the last mentioned ones return the constructed object so that it can be referenced later. In the case of the turtle this gives us the opportunity to have more than one turtle at a time.

Working with more than one turtle shows a serious disadvantage of the above definition: The code references always the same turtle. Thus the reusability is limited. The function should better be implemented as follows:

```
def rectangle(thisTurtle,a,b):
    for i in range(2):
        thisTurtle.forward(a)
        thisTurtle.turnDown (90)
        thisTurtle.forward(b)
        thisTurtle.turnDown(90)
```

For using more than one turtle there are several more or less meaningful applications. A less meaningful but instructive application is this: An area could be shaded by having two turtles drawing the outline and a third shading-turtle to walk from one to the other and back again (Fig. 1).



```
Ta=Turtle3D()
Tb=Turtle3D()
T=Turtle3D()

Ta.forward(8)
Ta.turnLeft(90)
Tb.turnLeft(90)

for i in range(10):
    Ta.forward(0.5)
    T.goto(Ta.pos)
    Tb.forward(0.5)
    T.goto(Tb.pos)

T.forward(2)
```

Figure 2. A shaded Rectangle built by three Turtles including the source code

A second perhaps more meaningful application is to implement a game of pursuit. An example can be found on our homepage.

OOP with Turtle3D

Using the turtle can also serve as preparation for object oriented programming. Each turtle has attributes (e.g. pen-color, pen-position, …) and own methods (forward, backward, …). These methods are already used the same way that will be relevant in object oriented programming: `objectName.methodName([args])`. To prevent misconceptions on distinguishing the concepts “class” and “object”, the students should use the opportunity to create two or more turtles from an early stage on. When introduced early, the students understand, why the turtle always has to be named (unlike in Logo) when calling a method and they understand `t1.penDown()` as an order to the turtle t1 to change its *and only its* state.

While using the turtle during our course, some students wanted to use their own written functions in exactly the same way as they used the built-in methods of the turtle – e.g. `t1.myFunction()`. If this wish shouldn't come up spontaneously it can be provoked by pointing out the difference between the "professional" build-in methods and the user's own procedures. Let's start with the following procedure to draw a circle (the rectangle above could serve as an example as well):

```
from VTools import *
from math import pi
t=Turtle3D()
t.setAnimated(False)

def circle(thisTurtle,radius):
    n=100
    for i in range(n):
        thisTurtle.turnLeft(360.0/n)
        thisTurtle.forward(2*pi*radius/n)

circle (t,5)
circle (t,8)
```

To have the drawing of circles on par with other built-in methods one would like to write e.g. `t.circle(5)`. Now, the restriction of Python (just like almost all other languages) is that you can't teach an old turtle new tricks (or in more technical language: one cannot add methods to a class or an object without changing the definition of the class). The way around is to create a new class of turtles that are cleverer than the original ones, a smarter descendant so to say:

```
class SmartTurtle(Turtle3D):
    def circle(thisTurtle,radius):
        n=100
        for i in range(n):
            thisTurtle.turnLeft(360.0/n)
            thisTurtle.forward(2*pi*radius/n)

t2=SmartTurtle()
t2.circle(10)
```

An important aspect that smoothes the passage to the OO language is that the definition to draw a circle could be repeated without change, it has just to be put into the body of a class statement. This step of abstraction is similar to the step of procedural abstraction used before:

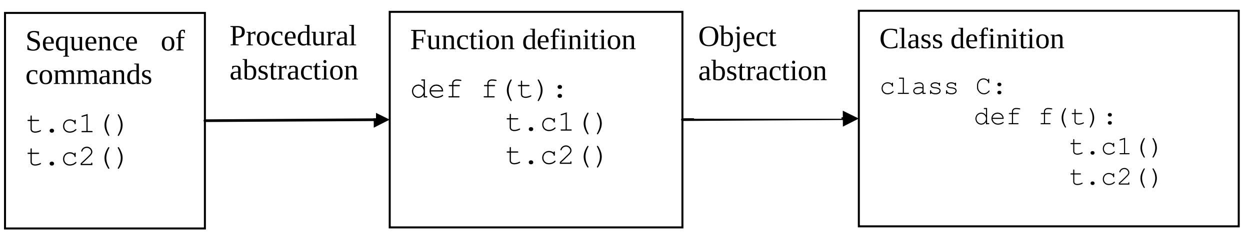


Figure 3. Steps of abstraction

A technical detail deserves attention: In Python the first argument of a method is usually called `self`. In the example above we have violated this convention in order to ease the transition from the purely procedural definition of `circle`. The advantage of this approach is that the role of this parameter becomes transparent. In the long run, however, it is advisable to urge the students to pick up the convention because `self` is a word that can be interpreted in almost all contexts.

An important feature of the introductory sequence described here is that inheritance is used at the beginning although it may seem that this is a more advanced concept that should be postponed. However, we profit from the fact that using objects from existing classes is very natural to students and poses hardly any difficulty. Taking objects from predefined classes is easy to understand as it complies with everyday knowledge of getting an object of a certain kind, e.g. getting a cup of coffee out of a coffee automat. Thus it is quite natural to work with things one already knows. In contrast, defining the first own class from scratch would is a much more abstract approach. Our approach is also close to the way OOP is used in most authentic applications (compare the arguments in Meyer, 2009 for using a large library from the beginning).

Forming a new, smarter class of objects by teaching them new things is a good mental image to understand the essence of classes and inheritance, it forms what we call basic conception (German "Grundvorstellung", cf. Rabel, 2011). While many other conceptions (e.g. class as a building plan or as a factory) address the understanding of attributes, this view is especially good at giving insight into the relevance of methods. While defining global procedures is to teach the computer new things, defining a derived class with new methods is to define new behavior for specific objects.

Empirical Evidence

A variation of the outlined course has been taught to high school students at two German schools as part of the course on computer science.

During the introduction course to procedural programming by 3D turtle graphics a student was very interested in adding more functionality to the turtle objects we used. Due to course plan this wish had to be postponed for a while. But when the students were introduced to object oriented Programming this particular student remembered his wish from one year ago and started to extend the given turtle class. He proudly presented that extension in a short talk. In the following we provide a transcript of this presentation:

Student 1: Sometimes it just annoyed me that the turtle itself could not rotate around its own axis, which means you could only turn left or right or up and down and not around the nose. And then we found out that you just, uh, turn up ninety degrees and after that you can turn to the left or right, and then back down ninety degrees. As you see, I implemented here [see fig. 4] that you can simply call it [the rotate function] like all the other turtle functions instead of troublesome programming by yourself. And, um, I just happened to have stumbled on it, how the shape of the ... how the turtle's shape is programmed. You can see it... here, well concealed from us, that there is another shape already: namely, the worm, all right? So here's the "TurtleForm". This is the turtle itself, as it is programmed, and the mentioned "WormForm" and uh, I went through it a little bit, uh, how it works, and then I programmed a little bit by myself: The "QuentinForm". Who knows Quentin [a figure from a German cartoon TV series]? Can everyone visualize that? Well, probably not. It is that yellow Ball.

Student 2 (from the audience): Ahhh, right!

Student 1: Then I have the ... uh ... Here you can ... Wait, I am going to label that first ... you can enter the shape and then subsequently I just put in the QuentinForm. The whole thing ... looks extremely funny, in my opinion ... And this is my new Turtle (smiles). So I find it extremely ... Yes, it is the result of boredom, but I think ... Now the mouth is gone ... There it is again. ... Well it came out of boredom and, uh, yes I think it is ... one sees that it is not ... not at all, not too difficult, to consider a new shape

... Yeah

Teacher: Very nice. And this (sporadic applause) ... You´re right, applause, please. ... Um, a short question, um: Have you implemented the rotate-function?

Student 1: Yes.

Teacher: Would you execute it, please?

Student 1: So, if you look here now, you see "rotateLeft" and "rotateRight" ... given and then you just put in the angle, how much ... So, for example I put in 90, then it turns 90 degrees ... respectively the other way around ... (Murmur from the audience) ... Quite a lot (murmur) ... which doesn´t have any effect ... It is back on top ... So I think, you can do a lot more with that [turtle class].

Teacher: Yeah! So, the tournament has begun. All of you can develop further. Super!

```
def rotateLeft(self,angle):
    """ rotateLeft(angle):

    The Turtle rotates counter-clockwise around its nose"""
    self.turnUp(90)
    self.turnLeft(angle)
    self.turnDown(90)

def rotateRight(self,angle):
    """ rotateRight(angle):

    The Turtle rotates clockwise around its nose"""
    self.turnUp(90)
    self.turnRight(angle)
    self.turnDown(90)
```

Figure 4. The student´s source code

This transcript shows clearly that the concept of inheritance was appreciated by Student 1 as the concept that solved his problem and his success was honored by others.

The episode illustrates as well a principle of our genetic teaching style: We try to introduce new concepts not quickly. Instead we try to get the students involved in situations where they get aware of problems to be solved. New concepts introduced are the solutions to problems not just new theory waiting for an example of application.

Conclusion

The teaching experiment described in this paper provides evidence that the 3D turtle is a motivating tool for high school students of age 16-17. There are further possibilities to keep the subject interesting: Listening to key events and detecting collision of graphical objects is easily done and allows the implementation of simple games. The visual effect can be made even stronger when using stereo display. This is sufficient for a unit of several weeks that touches all basics of algorithmics and OOP. Of course, the knowledge acquired there must afterwards be transferred to other application areas, e.g. to non-visible objects.

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Children's Reasoning about Samples and Sampling in a Project-Based Learning Environment

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Abstract

Building connections between sample and population lies at the heart of informal statistical inference (Pratt, Johnston-Wilder, Ainley and Mason, 2008). As Zieffler, Garfield, delMas and Reading (2008) point out, informal reasoning about statistical inference is the way in which students build connections between observed sample data and unknown or theoretical populations, and the way they make arguments or use data-based evidence to support these connections. The present study aims to investigate children's reasoning about samples and sampling in a project-based learning environment. Children analyzed collected data using TinkerPlots® as an investigation tool, and made a presentation of their findings to the whole school. The research aimed at providing detailed information about upper elementary school children's developing knowledge and intuitions regarding key statistical concepts related to samples and sampling, the type of informal inferential reasoning and thinking possible for the specific age group, and supportive instructional activities. Findings from the study suggest that the use of dynamic statistics software has the potential to enhance statistics instruction by making inferential reasoning accessible to young learners.

Keywords

Sampling, Sample, Informal Inferential Reasoning, TinkerPlots

Literature Review

Most of the research on children's reasoning about samples and sampling conducted in the past had primarily focused on understanding current conceptions rather than on developing them over time (Makar et al., 2011). Recent research, however, has shown that young children can demonstrate quite sophisticated levels of informal reasoning about samples and sampling if provided with an interesting and motivating learning context. Gil & Ben-Zvi (2010), for example, studied reasoning about sample and sampling among Grade 6 students (age 12), in the context of a collaborative, project- and inquiry-based learning environment designed to develop their informal inferential reasoning. They witnessed significant development of children's reasoning about key conceptions related to sample and sampling.

Although recent research on informal inferential reasoning has shown some promise in helping children develop deeper understanding of samples and sampling, research in this area is still at an infant stage. The current study contributes to the existing literature by investigating ways to support the development of primary school children's sampling conceptions in the context of making informal statistical inferences.

Advances of technology provide new tools and opportunities for the opening windows on mathematical thinking (Noss & Hoyles, 1996) . Having such a set of tools widely available to young learners has the potential to give children access to advanced statistical topics including inferential statistics and the broader process of statistical investigation (Makar & Rubin, 2007), by removing computational barriers to inquiry. This leads to a shift in the focus of statistics instruction at the school level from learning statistical tools and procedures (e.g., graphical representations, numerical measures) towards more holistic, process-oriented approaches that go beyond data analysis techniques (Makar & Rubin, 2007). Statistics can be presented as an investigative process that involves formulating questions, collecting data, analyzing data, and drawing data-based conclusions and inferences (Guidelines for Assessment and Instruction in Statistical Education (GAISE) Report, 2005).

Sampling reasoning is at the core of statistical investigations. Sample size and sampling method are the main determinants of the validity of statistical inferences. Despite, however, the central role of sampling in statistics, there has been relatively little research into the development of students' sampling cognitions. Among the few conducted studies on children's early conceptions of samples and sampling are the studies of Jacobs (1999) and Schwartz et al. (1998) who investigated Grades 4 and 5 children's informal understanding of sampling issues in the context of interpreting and evaluating survey results. They found that children's distrust of simple random samples and preference for stratification of the sample or for self-selection was attributed to their pre-occupation with issues of fairness and the wish to ensure representation of the diversity in the population in the sample. Also, children were more likely to identify potential bias issues in restricted sampling methods than in self-selected methods. Watson and Moritz (2000) investigated the characteristics of children's constructions of the concept of sample, and identified two key ideas for developing the sampling concept: appreciation for variation in the population and sensitivity to bias. The authors have found a trend for higher level performance with increasing age. The youngest children in their study (Grade 3, age 8-9) had fairly primitive, idiosyncratic notions of samples and sampling derived from everyday experiences with sample products or medical-related contexts.

In a study of high school students, Rubin et al. (1991) found a tension existing between the ideas of sample variability and sample representativeness. On most instances, students' comments suggested that they over-relied on sample representativeness, believing that a random sample has to be representative of the population, and that not randomness but some other mechanism must have caused sampling variability. Similarly to Rubin et al. (1991), Watson and Kelly (2006) found that elementary and middle school students often express beliefs that in a sample "anything can happen". Saldanha and Thompson (2002), who designed a teaching experiment to develop senior secondary students' concept of sampling distribution, found that due to lack of a suitable sense of the variability and the repeatability of the sampling process, students tended to judge a sample's representativeness only in relation to how different they thought it was to the underlying population parameter and not on how it compared to a clustering of the statistic's values.

Concurring with Clements and Sarama (2007), we espouse hierarchic interactionism, a theoretical framework which views children's development of mathematical reasoning as resulting from an interplay between internal and external factors, including innate competencies and dispositions, maturation, experience with the physical environment, sociocultural experiences, and self-regulatory processes. According to hierarchic interactionism, most content knowledge is acquired along developmental progressions of levels of thinking. These progressions play a special role in children's cognition and learning because they are particularly consistent with children's intuitive knowledge and patterns of thinking and learning at various levels of development, with each level characterized by specific mental objects (e.g., concepts) and actions (processes). The children's environment and culture affect the rate and depth of their learning along the developmental progressions. Instruction based on learning consistent with natural developmental progressions is more effective, efficient, and generative for the child than learning that does not follow these paths.

The present article contributes to the emerging research literature on the early development of informal inferential reasoning by focusing on children's understanding of sampling issues. Moreover, it describes the interaction between children and the dynamic environment of TinkerPlots as a trajectory for expressing the idea of sample. Building connections between sample and population lies at the heart of informal statistical inference (Pratt et al., 2008). As Zieffler et al. (2008) point out, informal reasoning about statistical inference is the way in which students build connections between observed sample data and unknown or theoretical populations, and the way they make arguments or use data-based evidence to support these connections. The present study aims to investigate children's reasoning about samples and sampling in a project-based learning environment. The research aimed at providing detailed information about upper elementary school children's developing knowledge and intuitions regarding key statistical concepts related to samples and sampling, the type of informal inferential reasoning and thinking possible for the specific age group, and supportive instructional activities.

Methodology

A teaching experiment was designed to promote understanding of sampling issues in a Grade 6 (11 year-old students) classroom. Nineteen children participated in data-centered activities, in contexts familiar to them, which provided them with opportunities to investigate real world problems of statistics using technology. They posed questions of interest to them, devised and carried out a sample data collection plan, and worked in small groups to formulate and evaluate data-based inferences using the dynamic statistics software Tinkerplots® as an investigation tool.

During the study, the research team collected and analyzed a wealth of data to assess students' growth in understanding and reasoning about samples and sampling. Students' learning processes were studied using written assessments, audio-recordings of class sessions, video-records of group sessions, interviews of selected students (the interviewing took place while students were working in groups for analyzing their data), and classroom observations and artifacts.

The videotapes collected during the course were first globally viewed and brief notes were made to index them. The goal of this preliminary analysis was to identify representative parts of the videotapes indicative of students′ approaches and strategies when performing specific statistical problem solving tasks. The selected occasions were viewed several times and were transcribed. The transcribed data, along with other data collected in the study, were analyzed in order to investigate children's ways of thinking about samples and sampling while informally drawing inferences from data. The results section shares some of the insights gained from the study regarding patterns and mechanisms of development in children's reasoning about samples and sampling.

Results

The main data source for the activities taking place during the teaching episode was a survey developed and administered by the children, which investigated the community service and volunteerism habits of students in their school. The development of children's volunteering ethos was a priority set by the Cyprus Ministry of Education for the entire school year. Students were introduced to the importance of involved and responsible citizenship in a cross-curriculum environment. Different subjects in the school curriculum aimed at fostering service learning, by informing children about the benefits of volunteerism and by encouraging them to get more actively involved in community service and voluntary work. A number of pro-social activities that provided volunteer opportunities for children were organized by the school.

Being sensitized to the importance of voluntary work, the sixth graders in our study decided to conduct a survey in order to investigate the status of school and community service among students in their school. Towards that purpose, they constructed a survey questionnaire. They worked in small groups, and then in a whole class setting, for finding 'important questions' to include in the questionnaire. The constructed questionnaire inquired students about their gender, age, whether they were familiar with each of the main volunteering organizations in Cyprus, and whether they wished to become members of such an organization. It also asked students to indicate the approximate number of times they participate each year in events organized by volunteering organizations, and to specify in which of a range of volunteer work activities planned to be take place at their school they would wish to participate.

Students participating in this research first completed the questionnaire by themselves and then decided to compare their answers with those of their classmates. Children analyzed the data and drew conclusions regarding the volunteerism habits of children in their class. Finally, they started thinking about conducting a survey of the students of the school in order to present their results to a school fair at the end of the year.

Next, students devised and carried out a data collection plan in order to obtain information about the volunteering habits of all students in the school. Given the large number of students in the school, they decided that it would be very difficult to administer the questionnaire to all students in the school. Instead, they decided to collect data from a sample of students from grades four, five, and six of the school. The sample selection process was decided after a long class discussion.

The following whole-class episode shows how students explore the need of having a representative sample from data.

Line 1	Teacher/Second author (T): So, what do you think? How can we get data for
Line 2	this survey?
Line 3	Student 1 (S1): We can get data only from 6th grade. Students at 6th grade are
Line 4	the oldest students at school and they will give better answers.
Line 5	Student 2(S2): But then, we cannot say that our survey comes from the whole
Line 6	school. What about the other classes?
Line 7	Student 3 (S3): *Why don't we ask all the students?*
Line 8	T: That's a good idea. What do others think?
Line 9	S4: Good idea. We need to split in groups of 2 and visit all the classes.
Line 10	T: But, think of having 220 questionnaires to analyze...
Line 11	S3: Is there another way to get a sample that *represents* our school?
Line 12	S2: Well, we need to have students from all the 3 grades. This is for sure.
Line 13	S4: Ok. Let's get the five students from the elected committee of each class.
Line 14	The children of the class voted for these students, so let's ask their opinion.
Line 15	S5: I don't agree with this. It is not fair. These students were selected to
Line 16	*represent* their class in the school's decisions, not to *represent* what all the
Line 17	students think. I didn't want to be in my class committee, but I would like to
Line 18	answer the questionnaire.
Line 19	S6: I agree.
Line 20	S7: Well, for having a *fair sample* of students, we also need to have the same
Line 21	number of boys and girls.
Line 22	T: Why do you think that?
Line 23	S7: We are different from boys. It is not fair to ask more boys than girls.
Line 24	T: So, what shall we do?
Line 25	S8: We need to select children by chance. Without knowing...
Line 26	T: How?
Line 27	S2: We can get the catalogue of each class. We need to select from each
Line 28	catalogue 5 boys and 5 girls.
Line 29	
Line 30	

The first reaction of some students (S3, Line7) was to ask all the students at school. It is interesting how the particular children came to the conclusion about the need to get a random sample. Fairness seems to be a big issue for them and this is also the reason for deciding to have a stratified sampling method (stratification by class and gender).

The teacher (Line 10) does an intervention in order students to start thinking of the idea of sample. This point was critical because in the following lines the students started to construct the idea of sample. They used phrases like 'that represents our school' (Line 11), and 'fair sample' (Line 20) to justify their decisions. It is also noteworthy that the first "fair decision" for them was to get data from all the students of the school (Line 7). It seems that the possibility of including the whole population, and the practical difficulties that this would entail, was the driving force for deciding to instead select a representative sample. The above episode shows also how the context of the survey influences the idea of having a 'fair' sample. The S5 girl was very interested in this project. This was one of the few times in which she expressed a wish to take part in a class activity. Her comments (Lines 15-18) were critical on continuing the discussion with children. In Lines 27-28, S2 suggests a way of getting a random sample. He suggested a random stratified sample. We believe that came easily to his mind, as children were very familiar to use the catalogue of the class. Actually, the class catalogue was used for absences, grading etc. The student knew that each class had a catalogue, so it was very easy to him to refer on it.

After collecting these real data about themselves and from a sample of students from the whole school, students worked in small groups to explore the data, using the dynamic statistics software TinkerPlots® as an investigative tool. The class was divided in five groups. Each group got one questionnaire, entered the data in a TinkerPlots datacard, got another questionnaire etc. Because of that, the final number of questionnaires in each group was different. In the end, Group A had access to 15 cases in their datacards, Group B had 26 cases, Group C had 4 cases, Group D had 21 cases and Group E had 31 cases. The big difference between the Group C (4 cases) and the other groups was because of technical problems with the laptop the group used. The teacher provided technical interventions here, that it wasn't worth to mention them.

Each group analyzed the data they had at hand and discussed their findings with each other. In group discussion, students tried to draw conclusions about the data they had in front of them. Firstly, they were making some data-based argumentations (Paparistodemou & Meletiou-Mavrotheris, 2008) like 'children in our data are willing to volunteer' (Student 2, Group A). Group A constructed the following graph (Figure 1):

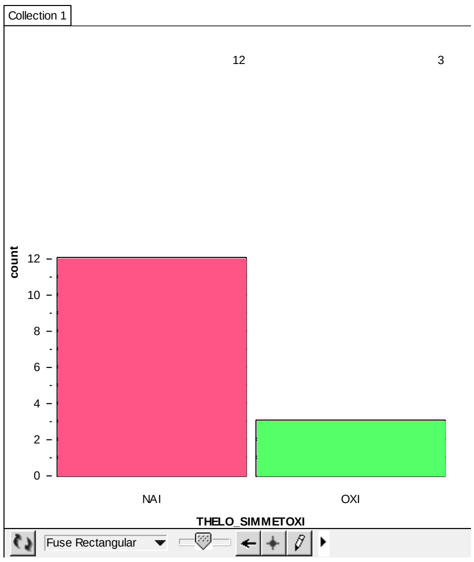

Figure 1: How many students of the data of Group A wanted to volunteer

('NAI'=YES, 'OXI'=NO)

Line 31 S2: We see children in our data are willing to volunteer.

Line 32 S1: From those that they didn't want to…Shall we check if there were boys or girls?

Children constructed another graph based on their question (see Figure 2). They added to their graph the attribute of Gender and they continued their thinking.

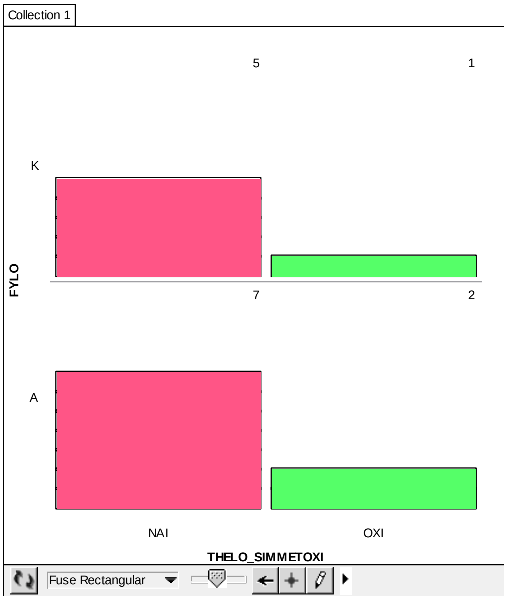

Figure 2: How many students of the data of Group A wanted to volunteer

('FYLO'=GENDER, 'A'='BOY', 'K'='GIRL')

Line 33 S1: From the children they said 'No', most of them are boys.
Line 34 S4: But, here we have a *sample of the sample'*. We need to see the graphs from all
Line 35 of our cases and this would be done at the end.
Line 36 S1: Let me see from which class these boys come from [she clicks on the particular
Line 37 part of the graph and look at the DataCard].

The above episode is an example of how children interacted with TinkerPlots in order to draw conclusions about their data. It is interesting how S4 express the meaning of the sample (Line 34). It seems to accept the results from the whole sample but need more evidence for drawing conclusions from a small number of data. Moreover, the children made some data-based argumentations and generalizations (Paparistodemou & Meletiou, 2008) like 'The whole school is willing to help' (Student 6, Group C), 'For most of our students to respect means to be kind'(Student 4, Group A).

After finishing with the datacards, the teacher (first author) got the different files from groups, and at the end she got all the cases in one file for analysis (97 cases). She then initiated a whole class discussion:

Line 38 Teacher: Let me open the cases of Group A. We have 15 cases. What do you
Line 39 think of the analysis of the results?
Line 40 S9: We need to say that all 15 cases were *randomly selected*.
Line 41 S1: Yes, but this sample is not *representative*. The children are not enough.
Line 42 S2: Ok. They were randomly selected, but they are not too many.
Line 43 S5: We cannot say that the findings from this group are the final findings.
Line 44 S10: *We need to have a file with all of the cases.*

Line 45 T: How about Group B's cases? Look, here we have 26 cases.
Line 46 S11: I think it is the same as before. *I think* that we cannot have only 26 cases,
Line 47 for analysing 220 [the total students of the school]. 26 students is the number
Line 48 of only one class.
Line 49 S4: But, it is better than having 15 cases.
Line 50 S2: Yes, it is better, but not enough. More children means more answers. That
Line 51 means we have a better opinion of what is happening in our school. A better
Line 52 opinion of what's happening, but not the best!
Line 53 T: So...I am not going to ask you about the 4 cases of Group C...
Line 54 S12: *Definitely* we cannot draw any conclusions. The number is too small.
Line 55 S2: Too small of a number. *That's for sure*. If we think that we have 116 more
Line 56 opinions...you can imagine...
Line 57 T: But our sample was randomly selected.
Line 58 S12: Is there a possibility of having 1 child in each class? If we have one child
Line 59 from each class, then with 3 cases we can say something.
Line 60 T: Hmm...
Line 61 S2: Do you think that one child from grade 4 can represent all grade 4
Line 62 students? Do you think that the questionnaire you filled for yourself can
Line 63 represent all grade 6 students?
Line 64 S12: No, but this is the least we can do. If we had 15 cases, but there is not
Line 65 even one grade 4 student in these cases, it is worse...
Line 66 S4: *Why don't we analyse all of our cases?*

The above snapshot shows how children come to realize the disadvantages of drawing generalizations about the population from a small sample. We recognize phrases like 'representative' (Line 41), 'randomly selected' (Line 42), but we also recognize that the number of the cases in a sample influence their opinion. In Line 46, the student uses the phrase 'I think', thus not making a strong statement about the 26 cases. In addition, in Line 54 and Line 55, students are convinced that they cannot draw conclusions from 4 cases. This is the reason that they use strong statements like 'definitely', and 'for sure'. Moreover, it is interesting how stratified sampling seems fair to them. The dynamic software helped children to construct multivariate graphs reflect on stratified sample. In Lines 58-65, S12 argues about having a random sample of 3 cases, but selecting it from all three grades. It is interesting that he is claiming that having a sample of size 3 is better than having a sample of size 15, if the sample of size 3 includes one child from each grade but the sample of size 15 does not.

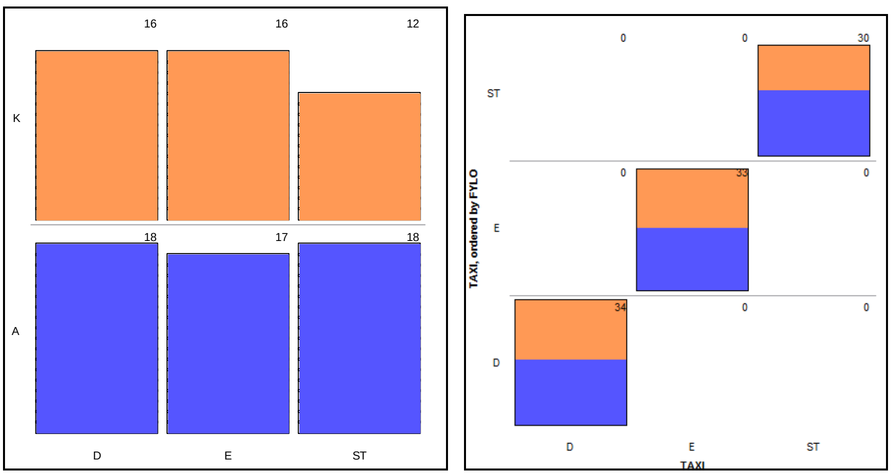

Figure 3: Number of boys and girls ('A'=Boy, 'K'=Girl) in each grade

('TAXI', where 'D'=Grade 4, 'E'=Grade 5, 'St'=Grade 6)

The following episode comes from the analysis of all 97 cases of their randomly selected sample. The children looked at graphs such as the ones in Figure 3 and drew some conclusions regarding the validity of the sampling scheme they chose.

Line 67 T: What do you think about our data?
Line 68 S7: Our numbers are good. You see, in grade 4 we have almost the same
Line 69 number of students as in grade 5 and in grade 6. The boys are a bit more...
Line 70 S2: Our method is *totally random*. So, having a bit more boys is ok.
Line 71 T: Do you think we can draw 'fair' results about our school now?
Line 72 S4: Yes....You see, now we have 97 cases out of 220 children. And you see,
Line 73 in in each grade we have *almost the same number of students* [in each class].
Line 74 T: So, is this a good sample?
Line 75 S2: Yes. Because it would be very difficult to collect data from all 220
Line 76 children. We chose these children randomly. I think they can represent our
Line 77 school.

In the above case, we see that children are satisfied with the sample selection process they had employed. They use phrases like 'totally random' (Line 70), 'almost the same number [in each class]' (Line 73) to express their satisfaction. Another issue that bothers them again is to ensure that their sample is representative of the whole population of students in their school. In Lines 75-77, S2 provides a justification for not collecting data from the entire population. Besides this justification, it shows that total fairness in results comes from asking the whole population. It is a strong statement that teachers can build on when introducing informal statistical inference in early mathematics instruction.

Conclusions

The 11-year-old students in the study experienced statistics as an investigative, problem-solving process. They formulated questions of interest to them and designed a survey instrument to use for data collection purposes. After a long discussion, they decided that it was more appropriate to use a sample of the population rather than a census to collect their data. They devised and carried out a sample collection plan to answer their research questions. This opportunity to experience the statistical problem-solving process through genuine collection and analysis of sample data, encouraged children to build, refine, and reorganize their intuitive understandings about samples and sampling. Their informal reasoning regarding the effects of sampling method and sample size progressed from rudimentary forms to more sophisticated ones. They began to appreciate the principles underlying sampling, and particularly the need for an adequately large sample size and a random-based sampling procedure.

The students in our study used the dynamic statistics software TinkerPlots® as an investigation tool. The presence of the dynamic software facilitated students' interest in the statistical investigation; it gave them the opportunity to explore data and draw data-based arguments and inferences in ways that would not have been possible for them without the software (Hammerman & Rubin, 2003) like interacting with a constructed graph (see Figure 1 and Figure 2) and drawing conclusions for two attributes at the same time (e.g. Figure 2). Attributes of TinkerPlots® like the ability to operate quickly and accurately, to dynamically link multiple representations, to provide immediate feedback, and to transform an entire representation into a manipulable object enhanced students' flexibility in using representations and provided the means for them to focus on statistical conceptual understanding. This study is an example of an approach to improving students' use of statistical reasoning and thinking by embedding statistical concepts within a purposeful statistical investigation that brings the context to the forefront. For young children like those participating in our study, personal experience and interest play a key role in learners' interactions with data. Our findings illustrate how young learners can begin to reason about sampling issues and other key inferential ideas when their interest in the task is high. Children's focus during their statistical investigations was on understanding the situation at hand, rather than on examining decontextualized data. Their engagement in an authentic, real world context encouraged students to seek ways to collect sample data that would enable them to draw valid inferences extending beyond their class to the whole school. The children were very much involved with their school project and the conclusions drawn from the data were important for them in order to understand what was happening at their school.

We focus our efforts on building sound foundations of inferential reasoning at a young age. As pointed out by Clements and Sarama (2007), young children possess an informal knowledge of mathematics that is surprising broad and complex. The current study and several other studies (e.g. Paparistodemou & Meletiou-Mavrotheris, 2008) have illustrated that when given the chance to participate in appropriate instructional settings that support active knowledge construction, even very young children can exhibit well-established intuitions for fundamental statistical concepts related to statistical inference. Through genuine data exploration, they can investigate and begin to comprehend abstract statistical concepts, developing a strong conceptual base on which to later build a more formal study of inferential statistics during high school and at the university level.

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Is this Constructionism? A case of young children, mathematics and powerful ideas.

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Abstract

In this paper I argue that Constructionism need not only be about computers and programming. In continuation to the themes discussed in Constructionism 2010, this paper argues that if Constructionism is restricted to the use of computers then constructionism cannot be applied in most educational settings around the world and builds on the assumption that schools and teachers should not be ignored but rather supported as to how to design activities that will formally lead children to powerful ideas. The paper describes an example of a learning experience in an early childhood education setting in Cyprus were 25 4-to-5 year olds used objects provided by their teacher to think with about powerful ideas. The learning experience did not involve computers but had all the main ideas of constructionism as expressed by Seymour Papert. It is a learning experience about young children, mathematics and powerful ideas.

Keywords

Young children, mathematics, powerful ideas

Introduction

As supported by Noss and Hoyles (1996), the computer has allowed 'glimpses to new epistemologies' and 'opened new windows on the construction of meanings'. This acknowledgement has always captured for me the origin of Constructionism but I had never though that it implied that in order to create learning experiences in a constructionist way you ought to use computers. I rather believed that it meant that computer-based research showed that provided sufficiently sensitive techniques are employed, learners might gain access to and communicate powerful ideas. Isn't that what Papert (1993) was talking about after all in '*Mindstorms': Children, Mathematics and Powerful Ideas*'? At least that is what I saw through the window which constructionism opened for me.

If we manage to move away from 'teaching children mathematics' to 'teaching children how to think as mathematicians' (Papert, 1972) isn't that learning in a constructionism sense?. If we manage to support children's learning-by making and thinking-as-constructing (Papert, 1991) and providing children with objects-to-think-with (Papert, 1993) isn't that what Constructionism is all about? Almost two years after Constructionsim 2010 I still hear voices in my head concerning what Constructionism is (or better say, is not). Should Constructionism be restricted to the use of computers and processes involving programming, or not? In the past, there have been examples of research within the constructionism paradigm that did not involve the use of computers (Papademetri, 2007).

If Constructionism is restricted to computers and programming then it is impossible to apply it to most educational settings around the world. In this paper I would like to describe a learning experience from an early childhood education setting in Cyprus. All public kindergarten classrooms in Cyprus have up to 25 3-to-5 year olds under the responsibility of one teacher.

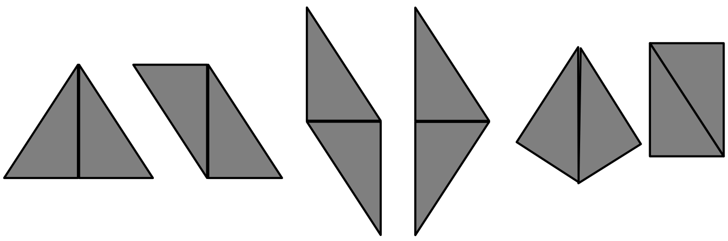
There is one computer in each classroom where the children can play normally during free play. The teachers are rarely and purely educated as to how to use the computer. Besides the restrictions of the setting in which the learning experience described in the following sections of this paper occurred, I would like to argue that this is a learning experience in a constructionist sense.

Methodology

The data presented in this paper originated from the implementation of an activity sequence in a public kindergarten in Cyprus. The activity sequence was implemented by a senior student-teacher in a classroom of 25 4-to-5 year olds in a public school within the children's everyday program. Children's time in public schools in Cyprus is shared between play time and whole classroom activities.

The activity sequence was designed as part, and in support of a much broader research project involving planning, implementing, evaluating and scientifically justifying a joint mathematics and science literacy curriculum for early childhood education, comprising by six common learning axes (experiences, scientific thinking skills, scientific thinking processes, attitudes, conceptual understanding, and epistemological awareness). This three year research project will end in August 2014. The joint curriculum is developed by a mixed group of researchers, content-knowledge specialists and educators, based on a review of existing literature and applications in authentic early childhood settings.

The task sequence was based on the following problem: 'How many different shapes can you make by putting together two congruent scalene, right-angled triangles so that one pair of congruent sides is always shared?' The idea for this problem originated by Claus (1992). In Figure 1 we illustrate all the solutions to the problem.



(a) (b) (c) (d) (e) (f)

Figure 1. The solutions to the problem.

The implementation of the activity sequence was videotaped and then transcribed. The transcript was then analysed in terms of the six learning axes. To be more precise, the effort was to identify among the data the learning outcome of the activity sequence in terms of the experiences the children gained, the scientific thinking skills, attitudes, conceptual understanding and epistemological awareness they developed and the scientific thinking processes involved. For the purposes of this paper we will focus also to those parts of children's learning that can be connected to the constructionism paradigm.

The activity sequence and results from the implementation

In this section we provide a description of the task sequence along with data from the implementation.

<u>Activity One: Introduction to the problem</u>

The student-teacher found an interesting way to get the children engaged in the problem described in the previous section. Besides the word triangle, none of the other mathematical terms of the problem was used to introduce the problem to the children. The children were asked through an interesting story to find how many different shapes they could make by using two given triangles and the problem was explained through an example of an acceptable solution and an example of an unacceptable solution. Through a discussion she had with the children, the student-teacher made sure that the children had understood the elements of the problem.

Activity Two: Experimenting and tracing solutions to the problem

At first the children worked in pairs were they **experimented** with a pair of the two congruent scalene, right-angled triangles while trying to find different solutions to the problem. The children were asked to find a way to remember their solutions so they decided that they had to trace each solution on a piece of paper (Figure 2).

Figure 2. The children are experimenting in order to find the solutions to the problem.

Activity Three: Presenting solutions to the classroom

Then the children presented their solutions to the whole of the classroom and through their drawings they concluded that they had found five different solutions to the problem altogether which they reproduced with the use of pairs of congruent scalene, right-angled triangles (Figure 3). The children did not identify among their drawings the solution illustrated in Figure 1(b).

Figure 3. The five solutions found by the children.

The children along with the student-teacher wondered whether there were more solutions to the problem. The student-teacher told the children that they would try and see if there are more solutions to the problem the next day and took photos of each solution found.

Activity Four: Observing the set of congruent triangles

The following day the children observed the two triangles they had used the previous day and made different observations. They observed that for each side of one triangle they could find the same side in the other triangle. Thus, as concluded by the children, the two shapes were 'the same'. They also observed that the three sides of each triangle were different between them. When the children were asked to find a way to show which side of one triangle was the same with which side of the other triangle they decided to use a different color marker to mark each set of equal sides. After they marked the two triangles the way they had decided, the teacher showed the children sets of triangles which she had marked earlier using blue, red and green.

Activity Five: Reproducing and observing the solutions to the problem

Then the student-teacher showed the children the photos from the solutions to the problem they had found the previous day and the children recognized that these were indeed their solutions. The children were separated into 5 groups. The student-teacher gave each group a photograph of one of the solutions they had found the previous day and 2 marked triangles. Each group used the triangles to reproduce the solution in their photograph. Then the children observed the 5 solutions found, as these were reproduced using the marked triangles (Figure 4).

Figure 4. The children are observing their solutions as reproduced with marked sets of triangles.

The student-teacher chose the solution illustrated in Figure 1c to start the following discussion with the children:

1 Teacher: *What do you observe about the sides you put together in order to make this shape?(Figure 5a)*

2 Child: *The two sides are open. One is right and one is left.*

3 Teacher: *What do you mean they are open? Explain to me.*

4 Child: *They are like the wings of a bird!*

5 Teacher: *A! The shape you made looks like wings. (Figure 5b)*
What else do you observe about the sides you put together?

6 Child: *They are the small ones.*

7 Teacher: *They are the small ones. What else?*

8 Child: *This shape when you put it the other way round looks like a tear.*

9 Teacher: *But in order to make this shape you put together two sides? The two sides are different?*

10 Child: *Yes. Because this goes straight down and this goes straight up. (The child points out one set of parallel sides of the shape, Figure 5c)*

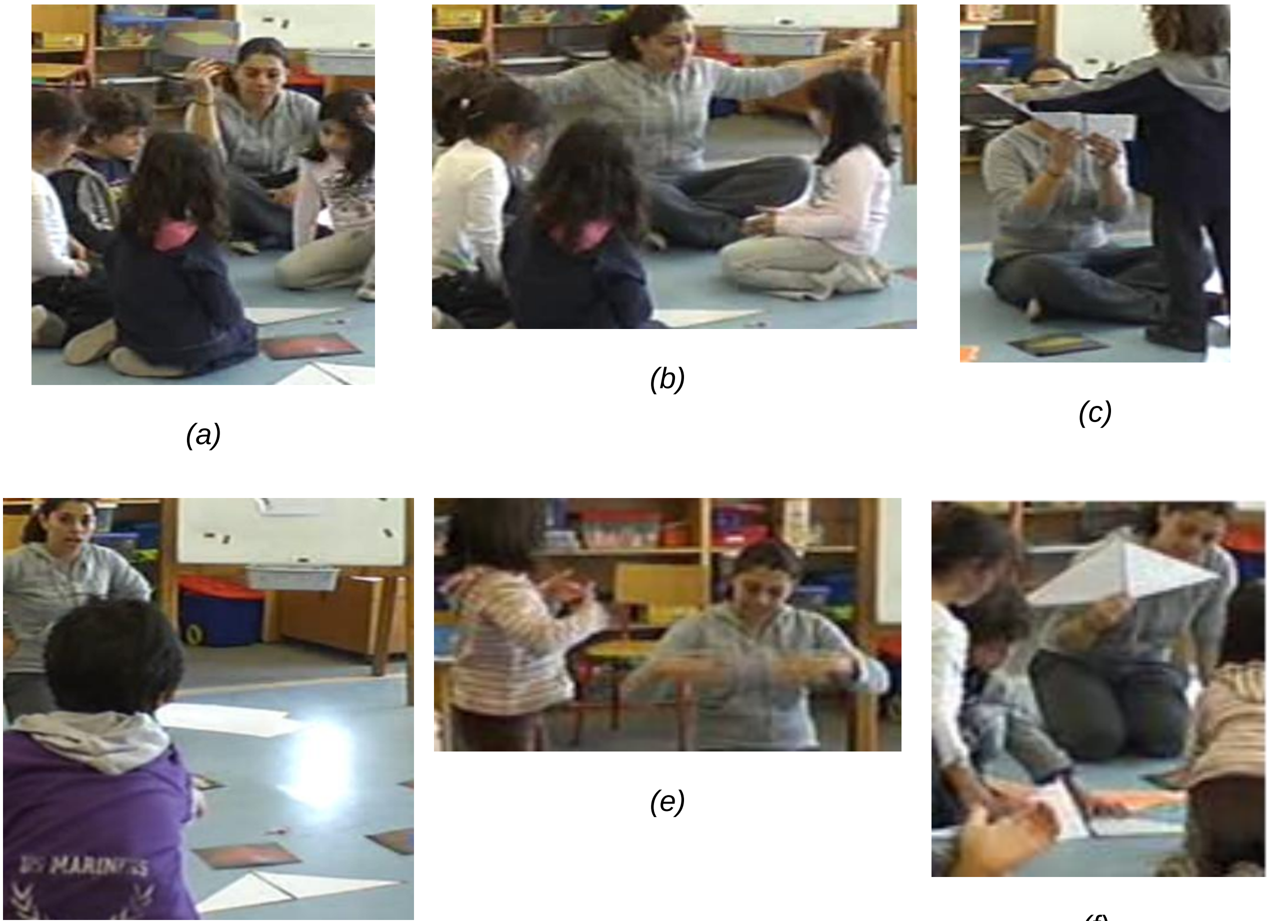
11 Teacher: *Nice? But I am talking about the sides the children put together. ....Observe their color.*

12 Child: *They are both blue.*

13 Teacher: *So they are ...*

14 Child: *...the same*

15 Teacher: *Do you see another shape which has the two blue sides joined?*
16 Child: *This one. (Figure 5d)*
17 Teacher: *How come we have two shapes with the blue sides joined?*
18 Child: *They were like this…(The child positions her two hands as shown in Figure 5e)*
19 Teacher: *And then …..*
20 Child: *…… the other way round. (The same child as before flips one of her two hands over)*
21 Teacher: *This looks like wings and this looks like a tear. How can we make the wings look like a tear?*
22 Child: *(A child after turning the one of the two triangles around for a while f l i p s it over.) (Figure 5e)*
23 Teacher: *What did you do?*
24 Child: *He turned it upside down.*



(a) (b) (c)

(d) (e) (f)

Figure 5. The children are discussing one of the solutions of the problem.

The student-teacher proceeded the same way with the two shape-solutions where the children put together the sides marked red and the one shape-solution where the children put together the sides marked green.

25 Teacher: *How many times did we join the red sides?*
26 Child: *Two*

27 Teacher: *How many times did we join the blue sides?*

28 Child: *Two*

29 Teacher: *How many times did we join the green sides?*

30 Child: *One*

31 Teacher: *So what do you observe? …… We have two solutions with blue, two solutions with red and one solution with green. Now open your ears because I have a question for you. Do you think we have found all the solutions?*

32 Child: *No*

33 Teacher: *How many more solutions are there?*

…….

34 Child: *There is one more solution.*

35 Teacher: *Why?*

36 Child: *Because …*

37 Teacher: *Let's think. Why is there one more? … How many solutions do we have for each color?*

38 Child: *Two.*

39 Teacher: *Two. Which color doesn't have two solutions?*

40 Child: *The green one.*

41 Teacher: *So, do you think there is one more solution for…*

42 Child: *...for green. Green is also two.*

43 Teacher: *Which is the solution missing? How can I have a different solution with the green?*

Two of the children tried to transform the 5th solution into another shape. Finally they flipped one of the two triangles over thus discovering the missing solution to the problem] (Figure 6)

44 Teacher: *So how many solutions do we have now?*

45 Child: *Six.*

Figure 6: The children are trying to find the missing solution

Findings

In Table 1 we can see the learning outcomes which were identified through the data collected from the implementation of the activity sequence.

Learning Axes	Learning Outcome of the activity	Corresponding

		Activity- Evidence
Experiences	You can make different shapes by combining two other shapes in different ways	Activity Two
	Two shapes might have their corresponding sides equal	Activity Two/Four
	There are triangles which have three unequal sides	Activity Two/Four
	Some problems have a specific number of solutions (there is a reason why the number is specific)	Activity Five
Scientific Thinking Skills	Collection of data	Activity Two
	Collection of observations	Activity Four/Five
	Interpretation of observation	Activity Five
	Formulation of a hypothesis	Activity Five
Scientific Thinking Processes	Problem solving	Activity One-Five
	Mechanistic reasoning	Activity Five
Attitudes	Experimentation	Activity One
	Collaboration	Activity One
	Continuation for the completion of a process	Activity Three-Five
Conceptual Understanding	Congruent triangles	Activity Four
Epistemological Awareness	Mathematical knowledge is based on empirical data and observations	Activity One-Five

Table 1. Tracing the learning outcomes of the activity sequence

In the previous section of this paper, we can see how young children were involved in a problem-solving activity were they had to construct shapes by using two congruent triangles, share and reflect upon their constructions. Reflecting upon constructions is a major issue within Constructionism (Kafai & Resnick, 1996; Papademetri, 2007; Resnick, 2007). Through the process and based on the analysis provided in Table 1, the children gained specific mathematical experiences, developed scientific thinking skills, attitudes, conceptual understanding about congruent shapes and their epistemological awareness and got involved in scientific thinking processes.

As far as experiences are concerned, this is a fundamental learning axis for the education of young children. As pointed out by Richard Noss during the Constructionism 2010 conference as part of the 'Constructionism Under Construction' Panel, 'engaged in constructionist activities makes it easier for teachers to teach difficult ideas later on'. In rephrasing this I would like to support the point of view that experiences are the basis and a prerequisite for conceptual understanding.

The children were involved in processes of flipping and rotating shapes (processes which remind us of Dynamic Geometry) while experimenting in their effort to find different solutions to the problem and in the process of trying to make and interpret their observations. Additionally these processes of observing and interpreting their observations (Activity five, discussion, lines 15-20) which led them to a formulation of a hypothesis (‘there is one solution missing’ ‘because green also has to be two’) is a process described by Russ et al (2008) as mechanistic reasoning.

Using a framework derived from the philosophy of science, Russ et al. (2008) developed a coding scheme of 7 major components of mechanistic reasoning that can be used to identify and assess children’s use of mechanistic reasoning. Those components include (i) descriptions of the target phenomenon (what we see happening), (ii) identification of the set-up conditions that are necessary for the phenomenon to happen, (iii) identification of entities (conceptual or real objects) that play a particular role in the phenomenon, (iv) identification of the entities’ activities that cause changes in the surrounding entities, (v) the entities’ properties, (vi) the entity organization (how entities are located, structured or oriented within the phenomenon), and (vii) chaining; that is using knowledge about causal structure to make claims about what has happened prior to a phenomenon and what will happen.

Based on Russ et all’s (2008) coding scheme for identifying mechanistic reasoning we can identify the components of mechanistic reasoning in the learning experience described earlier. The children made observations (described what they saw happening) – there are two solutions for the same set of congruent sides (Russ et all’s (2008) component i). In order to do that, the children identified the data of the problem (identified the conditions and described the entities which played an important role in the phenomenon) – this phenomenon arose while trying to construct shapes by putting together two congruent scalene triangles so that one pair of congruent sides is completely shared (Russ et all’s (2008) component ii-vi). After the children described what they saw happening they became involved in a chaining procedure where they tried to interpret their observation which allowed them to formulate a hypothesis in relation to the missing solutions to the original problem – there are two solutions for each set of congruent sides which result when flipping over one of the two triangles, thus the total number of solutions to the problem must be 6 (Russ et all’s component vii). This process of observing something interesting happening and trying to interpret this observation is so familiar when thinking about children playing with computers and observing interesting things happening on the screen within the constructionism research paradigm.

In concluding with the findings, I would like to pinpoint the ways in which the objects provided to the children operated as communicative and meaning construction tools. In Papademetri (2007) through a focused investigation of young children’s understandings of squares we concluded that ‘in the process of the tasks (designed for the aforementioned research) the children articulated, through the language provided by the setting, rich intuitive understandings about the structure of squares and were, at the same time able to situate their abstractions in the context of construction’. In the study by Papademetri (2007) the children went through a three phase task sequence consisting by a Description Task (the children were involved in classification and shape recognition tasks), a Construction Task (the children were asked to construct squares with the use of sticks) and a Reflection Task (the children were asked to reflect on the construction process). Even though during the Description Task, the children as supported by existing research exhibited limited understanding about squares, through their involvement in the Construction Task, they exhibited much richer intuitive structural understandings. And in the Reflection Task even though the children in a great extent failed to express about the structure of squares in formal ways they expressed about the structure of squares in diverse and inventive ways. As concluded by Papademetri (2007) ‘construction became the language the children could ‘speak’ and the adult (researcher/teacher) could ‘hear’. Similarly, in the task sequence described in this paper and through the children’s involvement we can see how the objects provided gave the opportunity to the children to think and communicate about powerful ideas without having to use formal language which is strange to young children. If we go back to Activity Four (observing the set of congruent triangles) we can see how the objects provided and the context of the activity allowed the children to think about and communicate their conceptual understanding of congruent shapes and scalene triangles. Similarly in Activity Five in line 10 of the discussion described in this paper we observe how the child refers and expresses his observations about the two parallel/equal sides of the parallelogram (Figure 1c) they constructed with the two congruent triangles. Thus here we have an example of the ways in which construction allows young children to think about, talk about, and reflect on mathematical concepts and phenomena.

Discussion

During the Constructionism 2010 conference as part of the 'Constructionism Under Construction' Panel, Richard Noss pointed out that 'powerful ideas mostly can't be learned by accident' stressing out the need for designing activities which will lead learners to powerful ideas. Furthermore this paper builds on the conviction 'that studies in mathematics education should involve some discussion of mathematical activity, however this is defined' (Hoyles, 2001).

In this paper we have described one such activity sequence and have argued that it is characterized by the main aspects of the constructionist approach. The children were given an-object-to-think-with, developed their scientific thinking skills and thus were taught 'how to think as mathematicians' learned through construction and reflection and gained access to powerful ideas. Based on Celia Hoyles comment in the Constructionism 2010 'Taking Stock' Discussion on assessment I can retrieve a substantial number of educational activities and pieces of research using computers (and claiming to be constructionism) that do not involve learning in a constructionist sense. Thus, the learning experience described in this paper is one example of how Constructionism can reach teachers and schools even in those cases were the conditions are not ideal and learning is not computer-based.

I would like to conclude this discussion with one final comment. According to Resnick (2007) 'Kindergarten is undergoing a dramatic change. For nearly 200 years, since the first kindergarten opened in 1837, kindergarten has been a time for telling stories, building castles, drawing pictures, and learning to share. But that is starting to change. Today, more and more kindergarten children are spending time filling out phonics worksheets and memorizing flashcards. In short, kindergarten is becoming more and more like the rest of the school.' We value Renick's conviction that 'exactly the opposite is needed: instead of making kindergarten like the rest of school, we need to make the rest of school (indeed, the rest of life) more like kindergarten.' Resnick (2007) is inspired by Kindergarten's traditional-authentic approach to learning in trying to formulate a Lifelong Kindergarten education. Because it is indeed a fact that Kindergarten is undergoing a dramatic (and quite sad) change, constructionism can replace kindergarten's lost identity and character. Thus it is time for early childhood education to be inspired (as paradoxical as it sounds) by constructionism.

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Friends of Papertian Constructionism

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Abstract
The expressed desire of the Constructionism Conference organizers to expand its horizons beyond Logo programming invites scholars to seek connections to others engaged in similar work and identify powerful ideas consistent with the theory of constructionism. This paper is intended to help raise awareness of constructionism beyond the Logo community while providing opportunities for constructionists to "think about thinking" through the prisms created by with a similar educational stance and the expansion of our community of practice. Each of the approaches explored in this paper are worthy of further study. Educology offers a lens through which to explore constructionism in a wider context.

Keywords
Progressive education, school reform

Introduction

Seymour Papert's contributions to education and the "big tent" of constructionism were striking during the Constructionism 2010 Conference in Paris. Papert's presence was palpable despite his physical absence. Each conference delegate represented a small piece of Papert's interests and intellectual output. There were the software designers, the teacher educators, the toy makers, the school reformers, the people concerned with how students understand a specific mathematical concept, those concerned with social justice, proponents of play, arts advocates and much more. When each of these constituent parts are stitched together as a complex quilt, Papertian constructionism extends beyond a theory of how learning most efficaciously occurs and represents a stance about education.

An oft-overlooked aspect of Papert's work was his interest in educology. In *A Critique of Technocentrism in Thinking About the School of the Future*, Papert uses the term educology as a plea for a more holistic theory of education of which constructionism is one branch. (Papert 1990)

> "*The word educology reminds us that we need a theory of education. One might say theories already exist. There is educational psychology; there is a theory of instruction; there are courses on the theory of how to administrate schools. But these are not theories of education as a whole. They are theories of small aspects of what happens in the educational process. By focusing on these small aspects, these trees and shrubs, we have gotten lost in the jungle.*
>
> *… I will take an example from my own work. People have asked, "What is the effect of Logo on learning mathematics -- or on planning skills or whatever?" Some experimenters have come up with very positive answers, some with negative ones. But they are*

> *barking up the wrong tree. They are following the methodology of studying the effect of something by varying one thing while keeping everything else constant.*
>
> *Such methods do quite well for studying the effect of a drug or a treatment for plants. But in the case of Logo, one sees its absurdity in the fact that the whole point of Logo is to make everything else change. One does not introduce Logo into a classroom and then do everything else as if it were not there. Such an approach completely misses the point. Logo is an instrument designed to help change the way you talk about and think about mathematics and writing and the relationship between them, the way you talk about learning, and even the relationships among the people in the school -- between the children and the teacher, and among the children themselves.*
>
> *The traditional methodology for studying innovation in education may have been adequate at a time when only small changes were possible, when in fact one did change an aspect of the mathematics curriculum and keep everything else the same. But we need a different methodology altogether when we envision radical changes in education."(Papert 1990)*

Situating constructionism in the context of a larger educology demands a more ecological view on learning – something Papert often discussed. Increased awareness of allies practicing constructionist-like approaches to education assists advocates of constructionism popularize their efforts and offers opportunities to learn the lessons of others engaged in sympathetic efforts. Constructionism matures when its practitioners have a greater range of contexts to consider and constructionism becomes more viable as an educational approach when its advocates develop alliances with similar movements.

Friends of Papertian Constructionism

Any proposed list of "friends of constructionism" would be incomplete, subject to debate and beyond the scope of this paper. However, Papert reminds us that "The most powerful idea of all is the idea of powerful ideas." (Papert 1980) A recognition that we stand on the shoulders of giants and are not alone in our attempts to create productive contexts for learning (Sarason 1990; Sarason 1996; Sarason 1998; Sarason 2001; Sarason 2004) offers sustenance to the constructionism community and aspires to achieve a greater impact than would be possible on our own.

Computers are critical to several of these "friend" while others might find their efforts enhanced by the addition of computational technology to their educational practice and objects-to-think-with. (Papert 1980; Ackermann 2010)

> "*One of my central mathetic tenets is that the construction that takes place "in the head" often happens especially felicitously when it is supported by construction of a more public son "in the world" – a sand castle or a cake, a LEGO house or a corporation, a computer program, a poem, or a theory of the universe. Part of what I mean by "in the world" is that the product can be shown, discussed, examined, probed, and admired. It is out there." (Papert*

1993)

"Learning by doing" improves upon traditional educational practice reliant on instructionism. (Papert 1985; Papert 1991) However, constructionism takes that one step forward with an emphasis on "learning by making."(Papert 1980s; Papert 1980s; Papert 1999)

The "friends of constructionism" described below represent many aspects of educology including technological empowerment, curricular improvement, authentic learning environments, kid power and the reinvention of what Papert would call School (with the capital S). They serve, as reminders that technological progress creates opportunities to amplify the potential of each learner and that John Dewey's ideas are alive and well. Things need not be, as they seem.

One Laptop Per Child

One Laptop Per Child (OLPC), the effort to invent a durable, affordable and powerful "children's machine" for kids in developing nations is the direct descendant of Papert's work and constructionist theory. After three million computers have been been given to children, the project remains as controversial as when it was first proposed. While there are legitimate criticisms of logistical and technical aspects of the initiative, OLPC continues to be attacked by those critical of the technology or its advocates. Papert and Negroponte have long predicted how institutions, such as schools, often display an immune response to new technologies and approaches to teaching and learning.

Since Alan Kay sketched his "dynabook" in 1968 following a visit to Papert's Logo Lab at MIT, members of the Logo/constructionism community have been committed to a personal computer for every child to be used as an intellectual laboratory and vehicle for self-expression. (Papert 1993; Johnstone 2003) OLPC's laser-like focus on learners, rather than schools casts its lot with constructionism over instructionism. OLPC has never been about schools or schooling. In some cases, schools were merely the distribution channel for children to receive laptops they can learn with anytime, anywhere.

> *"The OLPC concept measures [sic: matches] with the idea that children can take charge of their own learning.*
>
> *Making videos, communicating, creating their own programs, our children will take charge of knowledge. I believe that having the individual computers–each child owns a computer and has it all the time–is the only way we can empower really learner-centered learning." (2006)*

The "problems" attributed to the OLPC experiment are predominantly criticisms of politics, leadership or the intransigence of school rather than of constructionism or personal computing for poor children. (Warschauer, Cotten et al. 2011) Nicholas Negroponte and Sugata Mitra's audacious experiment to drop computers from a helicopter over a remote African village is based on a belief in constructionism. (Hruska 2011; Venkatraman 2011; Warschauer, Cotten et al. 2011)

> *"The computer greatly expands what is in the culture of the child's life. What the computer does is to make it possible for natural learning, which really means learning without teaching, without being taught, to be extended [exposed] to a much greater range of knowledge. I think we see when kids learn by themselves, to use the computer and to play very complex games, and overcome technical*

> *problems, we see them exercising the same natural learning abilities that enable them to learn to speak, learn to get around their parents, find the way around the house and find the way around the parents et cetera, all the stuff they learn outside of school. That's the natural learning.*
>
> *I agree completely with the suggestion [that] when they learn the computer, they are able to exercise that natural learning skill. But the conditions of school forces them to use more artificial ways of learning. So the big impact of putting out more computers under the control of children is to promote learning, learning. We will promote the learning of being a better learner, and that's the most important skill in a rapidly-changing world."(2006)*

Generation YES

Founded by veteran Logo educator, Dennis Harper, Generation YES is a US non-profit that create materials to support student empowerment around computer use. Generation YES employs kid power (Papert 1996; Papert 1998) to serve their community through the provision of teacher professional development, technical support and peer certification of technological literacy. Papert praised the program as one of the best things the United States Department of Education ever funded. (Generation_WHY 1998)

Fab and Personal Fabrication

Neil Gershenfeld, a colleague of Papert's at the MIT Media Lab directs the Center for Bits and Atoms and teaches a course entitled, "How to Make Almost Anything." Gershenfeld's book, *Fab: The Coming Revolution on Your Desktop--from Personal Computers to Personal Fabrication (Gershenfeld 2007)*and subsequent articles (Mikhak, Lyon et al. 2002; Gershenfeld 2005; Johnson 2005; Malone and Lipson 2007) predict that the next major innovation in technological progress will be personal manufacturing – creating the technology *you* need to solve *your* problems. Such self-reliance, personal empowerment and agency over technology have been at the core of Papert's work for forty-five years based on the question of whether the computer programs the child or the child programs the computer? (Papert 1980)

> *"I thought of giving children the power to program computers as a tiny first step in a complex process whose details could not be anticipated.* (Papert 1997)

Throughout his career, Papert has not only advocated children owning personal computers, but maintaining, repairing and even building the computer themselves. Fab brings us one step closer to that ideal.

> *"Looking at the complex texture of Logo development provides a new perspective on the problem of deciding not only whether Logo succeeded or failed, but whether all endeavours in the field have succeeded or failed.*
>
> *The problem is not so much solved as dissolved: the real problem is not whether Logo "succeeded," but understanding the growth of a computer learning culture in which Logo plays an important, but not determining, part. Does this mean we can simply drop Logo? Yes but only when Logo is given its ultimate success by the*

> *evolution of the next stage of programming systems for children."*
> *(Papert 1997)*

Precedents for the much more technologically sophisticated fabrication predicted by Gershenfeld and represented by the exploding "maker" community of tinkerers and inventors promoted by *Make Magazine* may be found in the creation of programmable LEGO robotics materials (Resnick and Ocko 1991; Resnick and Ocko 1991; Papert 1993; Resnick 1993; Kafai and Resnick 1996; Resnick, Bruckman et al. 2000). Papert's affection for bricolage (Papert and Franz 1987; Papert 1991; Turkle and Papert 1992; Papert 1997) as an important element of knowledge construction is well represented by the hobbyists and children engaging with increasingly sophisticated technology in a personally expressive fashion.

The growing popularity and expanding network of community-based "hacker spaces" are high-tech "samba schools" (Papert 1980) where expensive fabrication hardware and expertise is shared with bricoleurs of all ages. (Schlesinger ; Lahart 2009; Raison 2010; Baichtal 2011; Hunsinger 2011; Holt and Braun 2012) Arduino, Lilypad Arduino and other new robotics construction kits have deep ties to Papert, his colleagues and constructionism. (Schelhowe ; Resnick 1993; Resnick, Bruckman et al. 2000; Eisenberg, Eisenberg et al. 2005; Buechley, Eisenberg et al. 2008; Katterfeldt, Dittert et al. 2009; Dittert and Schelhowe 2010)

The popularity of reality television is in no small part based on the sharing of what Papert called learning stories. (Papert 1993; Papert 1993) Papert's prediction of a knowledge machine as exemplified by a preschooler asking the computer, "How do giraffes sleep?" (Papert 1993; Papert 1993) becomes more of a reality each day due to the availability of the Web, YouTube and reality television. Expertise is more easily accessible than at any time in history. Knowledge and apprenticeship experiences are but a screen away. Coupled with the ability to use technology to invent solutions to personally meaningful problems, learners not only have access to information, but a greater ability to shape their world. Personal fabrication furthers Papert's vision that "If you can use technology to make things you can make a lot more interesting things. And you can learn a lot more by making them." (Stager 2006)

Samba Schools

The Brazilian samba school is one of the most enduring metaphors in *Mindstorms*. (Papert 1980) The samba school is where people of all ages come together to prepare for their dance in the annual carnival parade. Young and old learn to dance together with a shared purpose and rich community of practice. Papert asserted that computer-rich environments such as where Logo was being used had a great deal in common with the samba school.

> *"Logo environments are like samba schools in some ways, unlike them in other ways. The deepest resemblance comes from the fact that in them mathematics is a real activity that can be shared by novices and experts. The activity is so varied, so discovery-rich, that even in the first day of programming, the student may do something that is new and exciting to the teacher. John Dewey expressed a nostalgia for earlier societies where the child becomes a hunter by real participation and by playful imitation. Learning in our schools today is not significantly participatory—and doing sums is not an imitation of an exciting, recognizable activity of adult life. But writing programs for computer graphics or music and flying a simulated spaceship do share very much with the real*

activities of adults, even with the kind of adult who could be a hero and a role model for an ambitious child." (Papert 1980)

Although Papert acknowledges that Logo environments are "too primitive" (Papert 1980) to satisfy the ideals of the samba school, at least three "friends of constructionism" have created learning environments that approach that standard of deep intergenerational learning.

"LOGO environments are not samba schools, but they are useful for imagining what it would be like to have a "samba school for mathematics." Such a thing was simply not conceivable until very recently. The computer brings it into the realm of the possible by providing mathematically rich activities which could, in principle, be truly engaging for novice and expert, young and old. I have no doubt that in the next few years we shall see the formation of some computational environments that deserve to be called "samba schools for computation." There have already been attempts in this direction by people engaged in computer hobbyist clubs and in running computer "drop-in centers." (Papert 1980)

Computation is not integral to 826 Valencia, El Sistema, Reggio Emilia or the Big Picture Schools. However, these projects have demonstrated a scalable and sustainable model for creating rich environments where children work alongside of adults in mutually beneficial learning adventures. Regardless of whether the leaders of these movements are aware of constructionism, their projects embody it at a scale constructionists should envy.

826 Valencia

826 Valencia is a community writing center started in 2002 by Nínive Calegari and best-selling novelist Dave Eggars in a diverse San Francisco neighborhood. Children spend their afterschool and weekend hours there writing alongside real writers. One could think of 826 Valencia as the literary equivalent of Papert's "Mathland."(Papert 1980) Kids are taught to be writers rather than taught about writing, just as in Mathland children are taught to be mathematicians rather than being taught math. (Papert 1972) They write for deeply personal purposes and for publication through regularly published anthologies and engage in many forms of writing including poetry, novels, non-fiction, criticism, journalism, social activism and more utilitarian artifacts, such as college essays. Volunteers, many of whom are professional writers, support the youngsters in the writing process. Notable authors occasionally sponsor the publication of a writing anthology organized around a specific theme and join their younger peers by contributing a work of their own in the same volume. (826Valencia)

The setting of 826 Valencia and its growing network of other centers (currently eight in the United States) is critical to its success in creating productive contexts for learning. The original San Francisco writing center is in the back of a pirate supply store, complete with planks, eye patches, a "fish theatre," scurvy medicine, hooks and any other provision a swashbuckler might need. Other 826 Valencia centers are built around themes such as time travel and super hero supplies. The whimsical settings are inviting to children, honors their playful spirit and creates a place in which they feel safe making their thinking visible via the often vulnerable act of writing. 826 Valencia also organizes and prepares thousands of volunteers to work in public schools as writing mentors in the cities they serve. (TED 2008)

The Big Picture

In 1995, serial American public school transformer, Dennis Littky, and his partner Elliot Washor the MET School in a poverty-ravaged neighborhood in Providence, Rhode Island. The MET and other similar schools became the basis for the Big Picture Schools, of which there are now more than sixty around the world.. (Big_Picture_Company) As in El Sistema, Reggio Emilia, 826 Valencia, Generation YES and the samba schools, Big Picture Schools rely on relationships between students and teachers who know and care for each other. While many of the other “friends of constructionism” discussed in this paper are informal learning spaces, the Big Picture Schools are a complete reinvention of secondary education.

Big Picture schools typically serve grades nine through twelve. Approximately fourteen students are assigned to an advisor who remains with them for four years. The advisor is responsible for educational progress and well being of a student while also serving as the student’s primary teacher *at school*. Students do not attend school at all two days a week. They engage in internships in the community based on anything that interests them. The curriculum back at school, Monday, Wednesday and Friday is anything that the student needs to know in order to do better what they do Tuesday and Thursday. No distinction is made between vocation and avocation, academic areas or vocational skills. Any passion the student follows in real-world settings with a mentor form the basis for their university-preparatory education. The Big Picture Schools also keep coercive practices such as grading to a minimum. Students present exhibitions of their work to the community of peers, advisors and mentors in a public setting as a way of demonstrating competency in the spirit of Ted Sizer’s work with the Coalition of Essential Schools. (Sizer, National Association of Secondary School Principals (U.S.) et al. 1984; Sizer 1992; Sizer 1996)

Despite this unorthodox approach to secondary schooling, students in the Big Picture Schools enjoy a very high percentage of entry to higher education and impressive academic. Most importantly, students who spend four years creating their own path not only develop the habits of mind to become competent lifelong learners, but they develop the social capital usually reserved for peers of much greater wealth and privilege. Littky has recently expanded the model to address high rates of higher education attrition among economically disadvantaged students through the creation of *College Unbound* while there are elementary schools exploring how the Big Picture principles may apply to primary education.

El Sistema

In 1975, Venezuelan economist and musician, José Antonio Abreu created El Sistema (The System) as a vehicle to create social cohesion in Venezuelan society in response to widespread poverty and violence. Abreu believed that once you give a violin to a child she is “no longer poor” (TED 2009) and “unlikely to pickup a gun.” Students from preschool through secondary school age study in community-based instrumental music, singing and music theory in community based nucleos across Venezuela, many in the poorest of communities. Each nucleo has one or many orchestras through which students progress based on ability. El Sistema also provides opportunities for students to play in regional and national orchestras. Being productive citizens is the goal of El Sistema, not the creation of professional musicians even though Venezuela is gaining a reputation for creating some of the finest musicians and orchestras in the world. (Smaczny and Stodtmeier 2009)

In the case of El Sistema, music is the object to think with. By being a musician in an orchestra, you learn about discipline, democracy, perseverance, excellence, listening, culture, precision, beauty, history and more. You are part of something larger than yourself. In a poor nation such as Venezuela, necessity is the mother of invention. A scarcity of instruments has led El Sistema to create “luthiers,” workshops where young people learn to build, repair and maintain musical instruments. The luthiers share much with Fab Labs and the construction of guitars in Papert’s Constructionist Learning Laboratory. (Stager 2006) Older students often teach lessons for less experienced children and even conduct orchestras. Students are expected to teach each other informally during orchestra rehearsals.

Once you receive an instrument you are in an orchestra playing classical music. If you only know how to play one note, a part will be written for you so that you can play that note on cue. The orchestra may be playing Mahler or Beethoven, but you *are* a musician in a *real* orchestra from day one. Abreu is driven by a belief that "poor children do not deserve poor music." (Tunstall 2012) Such principles and pedagogical techniques should resonate with constructionists and share much with the other "friends of constructionism."

El Sistema and The Big Picture Schools have achieved the holy grail of innovation – scale. Close to a half million children participate in El Sistema annually and the global popularity of "The System" has been amplified by the Los Angeles Philharmonic's hiring of Gustavo Dudamel at twenty-five years old as its principle conductor. Acclaim for the energetic, charismatic and gifted Dudamel has helped spread El Sistema based on his outspoken promotion of "The System." His evangelism is rooted in the fact that he was a child who came up though El Sistema and at such a young age is now considered one of the world's premiere conductors. Dudamel presides over a version of El Sistema in Los Angeles.

Reggio Emilia

Perhaps the most outstanding implementation of constructionism may be found in the more than thirty infant-toddler centers and preschools in the Italian city of Reggio Emilia. Fifty years ago, Loris Malaguzzi led a group of educators who wished to rebuild their post-war city based on the rights and competency of its youngest citizens. "The Reggio Approach" is built on a child's curiosity, interest and passion. It is only an accident of bureaucracy that the Reggio Approach is so closely associated with preschool education. Its powerful ideas have application to education at all levels.

> "*It is close to 40 years since I fell in love with the idea that a technologically rich environment could give to children who love ideas access to learning-rich idea work, and to those who love ideas less the opportunity to learn to love them more. But many ideas are more easily loved than implemented. What is idea work? How can it be made accessible to young children?*" (Papert 2000)

Reggio Emilia has done more to make idea work accessible to children than perhaps anywhere else in the world and they have done it for half a century. In Reggio, the teacher's primary role is as a researcher who makes each child's thinking visible through careful listening, documentation and analysis with colleagues. The teachers then prepare the environment to be the "third teacher" supporting further inquiry. Malaguzzi, one of the great educational philosophers of the past century said that the learning environment should be comprised of one thousand laboratories designed carefully to support the hundred languages of children. Students in Reggio centers learn free of coercion and express their intellect and creativity through artifacts and projects of staggering beauty and complexity. They use real materials to solve authentic problems. "Knowing Reggio" is as complex or difficult as knowing Papertian constructionism and requires much more space than this paper allows. However, a growing number of books and DVDs illuminate why *Newsweek* called the Reggio preschools among the best schools in the world. (Kantrowitz 1991)

Papert was fond of El Sistema, although I am unaware of whether he ever met Maestro Abreu. I do know that he had visited Reggio Emilia, but am uncertain if he ever spoke with Malaguzzi.

Abreu, Littky, Malaguzzi, the educators of Reggio Emilia and Seymour Papert share the same critical trait; a steadfast refusal to succumb to incrementalism. The municipal preschools of Reggio Emilia have achieved a sort of longevity that should be admired by constructionists everywhere. Advocates of constructionism have much to learn from progressive educators engaged in similar work, regardless of whether computation is involved, while constructionist theory will find a larger audience through alliances with those similarly inclined. Such bridge building contributes to a more mature educology benefitting us all.

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A Framework for Characterizing Changes in Student Identity during Constructionist Learning Activities

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Abstract

In this paper we present a framework for examining meaningful changes in students' identity in relation to science and engineering. These identity changes could represent useful indicators for characterizing student engagement and interest in constructionist, project-based learning environments. The framework is described using data from a study with 12 high-school students that in which learners spent 6-hours a day in a digital fabrication lab for eight weeks.

Introduction

Recent work has highlighted that future career choice in science, technology, engineering and mathematics (STEM) fields is better predicted by students' interest and engagement than with academic achievement and course-taking (Maltese & Tai, 2011). Decades of prevalence of traditional instructionist approaches make this finding unsurprising, however, these new results are revealing an even clearer picture of the state of STEM education and bringing issues of motivation again to the forefront of the research community. As we consider interest and engagement, it seems apt to reflect upon what elements are central to these two concepts. In considering this, we draw upon *identity* as being integral to understanding, and characterizing, interest and engagement.

Accordingly, this paper presents a methodology for recognizing elements of student language that cue important aspects of their identity. Additionally, we present hypothesis and theoretically grounded arguments for understanding how these cues relate to student persistence and development.

We proceed by describing the theoretical underpinnings that we use to characterize student identity, followed by a brief description of the data set. We then move on to an in-depth discussion of our analysis, and, finally, discuss the emergence of certain identity traits through qualitative analysis of student discourse using our framework.

Theoretical Framework

Identity

The term identity can be associated with many different things and is often invoked at different scales. Viewpoints of identity have also experienced several changes in recent times. There has been a gradual shift from the "romantic" view of identity, in which one's identity was seen as a static entity that one has from birth, often times attributed to socioeconomic status, or social class; to the more modern view of identity as being a socially constructed, multi-faceted, dynamic set of personal characteristics (Lee & Anderson, 2009). These characteristics are ones that can change over time, are relative to one's peers, and subject to multiple interpretations by others. Nonetheless, a central idea that has persisted about identity is that it is a way of defining or describing an individual's discourse – behaviors, speech and thoughts. This is the level of understanding identity that we will use in discussing changes in students' identity in this paper. Furthermore, for the purposes of this paper we are primarily concerned with identity in terms three dimensions: *identity in language* - how individuals talk about themselves in relation to other entities; *identity in conflict* - the explicit and implicit conflicts in an individual's identities; *identity in development* - the ways that an individual's identity has come to be developed. We briefly highlight key elements of each of these three dimensions and their theoretical grounding, but present them more comprehensively in the Discussion section.

Identity in Language: The Language of Identification

Identity in language is characterized by an individual's verbal discourse and the use of phrases such as "I am …", "we are …" and "it is." Here we posit that students' choices of "I", "we" and "it", are cues into the relationship that the individual has with other individuals and other objects within the learning environment, including artifacts created by them. Furthermore, we will look at how individuals choose to present information to others, either in a way that the speakers treats themselves as superior, equal or inferior to the listener. Some of this analysis is based on previous research on how experts and novices talk about different external entities, (Worsley & Blikstein, 2011) as well as linguistic analysis of science learners (Heath, 2012).

Identity in Conflict - Explicit and Implicit Identity Conflict

The second dimension for analysis falls along the lines of identity conflict. Different from previous work on identity conflict (Agar, 1997, Fordham 1999, and Lee & Anderson, 2009) our framework looks at cases where an individual may have adopted a certain identity without having fully achieved that identity. For example, one can imagine a teenager who identifies him/herself as an adult. We see that this type of conflict can exist in both a positive and negative light, and we explore the implications of these identity conflicts as we analyze the data.

Identity in Development - The Nature of Establishing and Developing an Identity

The final dimension that we analyze relates to the elements that help students develop or maintain a given identity. In order to examine this dimension we are interested in looking at the ways that an identity is formed, in terms of acquisition or learning (Gee, 1999) and the external factors that help promote the development of that identity. According to Gee (1999), Yoder (2000) and Wenger (1999), the formation of identity is *experiential*, and is not formed in isolation. Accordingly, we look at ways that external factors influence identity formation as a lens for analyzing individuals' perceived identity.

Data

The data for this study comes from 12 high school students that participated in a two-month digital fabrication and invention class. Students worked in a constructionist environment, being situated in a hands-on, multi-disciplinary environment where they were challenged to do a variety of STEM activities and build a variety of artifacts (Papert 1980, 1991). Students participated in a special program that replaced the 6 hours that they would normally spend at school, with an opportunity to engage in construction of meaningful artifacts and ideas. The high school students were predominantly in the 9th grade; three of the students were females. All of the students self-selected to take part in the study by signing up for a digital fabrication and invention class at their high schools. Students worked with a team of 15 teaching assistants that would take turns facilitating the activities. Projects were student-directed and involved environmental engineering, robotics, electronics, mechanical engineering, engineering design, music, art, computational modeling, physical fitness, and more. All of the projects required the students to learn a new piece of technology, and typically involved computer programming in NetLogo (Wilensky, 1999) or in Cricket Logo (a version of Logo customized for the GoGo Board (Sipitakiat, Blikstein, & Cavallo, 2004; Blikstein & Sipitakiat, 2011). Approximately half of the projects were collaborative, while the other half were individual. Students worked on a given project for three to four days prior to presenting their work to their peers. Finally, at the conclusion of the class, students presented their work to teachers, parents and researchers.

Students participated in one-on-one interviews with a member of the teaching staff in one month increments. The one-on-one interviews consisted of questions that asked students to design a certain invention or device. For example, one of the questions was to design a piggy bank that automatically counts the money as it is dropped in. There were also questions that asked students to explain a certain social or natural phenomena that can be characterized by exponential growth or power laws, a principle that they explored extensively since one of the sections of the activities was dedicated to agent based modeling. All interviews were transcribed, and serve as the primary component in the discussion that follows. Transcripts ranged in length from 15 to 40 minutes

Data and Discussion

Identity in Language: The Relationship between "Me" and Other Entities

In this section we examine the way that people talk about themselves in relation to the machines that they built, and the models that they were asked to explain. In Table 1, we present the frequency of 'I' (or 'we'), 'you', 'it' and 'the' occurred within a spoken utterance.

Pseudonym	I	you	it	the
Gunther	0.34	0.34	0.04	0.27
Francis	0.23	0.05	0.24	0.48
Thomas	0.25	0.05	0.36	0.34
Peter	0.20	0.17	0.32	0.31
Eric	0.36	0.05	0.30	0.29
Kyle	0.05	0.07	0.36	0.53
Violet	0.16	0.13	0.45	0.25
Shannon	0.28	0.14	0.16	0.42
Sadie	0.24	0.05	0.30	0.42

Table 1 – The fraction of 'I' ('we'), 'you', 'it' and 'the' in student exit interviews 1 month into the program

Since for now we are simply counting word frequencies without any consideration for the context, the goal is to simply investigate if there is any approximate regularity or pattern in the use of such words, even given the open-ended nature of most of the interview questions. Table 1 immediately reveals Gunther and Eric as outliers in their relatively high use of 'I,' 34% and 36%, respectively. This is in contrast to Kyle, who only used 'I' in 5% of the times where he used 'I', 'you', 'it' and 'the.' Gunther also demonstrates an extensive use of 'you', 34%. Gunther is a unique case on the opposite extreme for use of 'it;' recording the word far less frequently than his peers. Finally, we see that Kyle uses considerably more 'the' utterances than any of his peers. While these numbers provide some insights, we are still left with a number of questions about what these words really signal about identity. For this analysis, we will turn our discussion to a deeper qualitative analysis, in order to highlight three distinct patterns in students' utterances in the interviews: using 'I' as a way to express a sense of connection and achievement; using 'the …' or 'it' to express a sense of disconnection; and using 'the …' or 'it' in conjunction with 'you' to adopt an instructional discourse – trying to teach the interviewer about something or simulating a teaching scenario. In the following paragraphs we present examples of each of these and discuss their significance.

'I' as a sense of achievement

Eric is a student who liked to work by himself. When asked to work in a group, Eric would typically relent and proceed to work on his own. During the first month of the program, Eric designed an alarm clock that he was quite proud of. Even though the alarm clock had not turned out as intended, it featured bright lights and an intricate design, and Eric received several compliments on his creation. It is telling to note that Eric used 72 'I' utterances in his transcript, with the majority of them being used while describing his alarm clock and how it functioned. Here is an excerpt from the transcript in which Eric uses several 'I' statements.

[03:22.0] Eric: Was, uhh, I used, wh < - > umm, my original design was to etch in a bunch of lines that I would then cover with the, uhh, what I would then use for the, umm, as my, like…

Uhh, like…I don't know what the word is. Like, guide for the, where I put the EL wire.

[03:44.0] Interviewer: Ohhh.

[03:44.7] Eric: So, umm, I then etched it in but then I realized that, umm, I used too many lines and they were all too close together and I wouldn't have enough connectors for EL wire to cover all the spaces, so then I just used less lines and…

[03:59.8] Interviewer: Mmhmm.

[04:00.1] Eric: I was then, I, I'm, I was still was left with a lot of etched lines left….

We see that the majority of Eric's utterances included the word 'I'. This is significant because Eric could have just as easily described everything about his alarm clock without ever using the word 'I.' Consider the transformation of the following sentences that produces the same description of the alarm clock's operation.

Original: Was, uhh, I used, wh < - > umm, my original design was to etch in a bunch of lines that would then cover with the, uhh, what I would then use for the, umm, as my, like… Uhh, like…I don't know what the word is. Like, guide for the, where I put the EL wire.

Without 'I' (or 'my'): Was, uhh, the original design was to etch in a bunch of line that would then be covered with the, uhh, they would then be used for, like…. Uhh, like…the word escapes me. Like, guide for where to put the EL wire.

The fact that Eric chooses to describe how he constructed his system making extensive use of the word 'I' is reflective of the sense of accomplishment that he had received by building it (Heath, 2012). Accordingly, he used more personal language as a way to share the depth of that personal connection.

Disconnecting From the System

When Eric was describing his alarm clock, his language was characterized as being very personal. However, after talking about his alarm clock, Eric was asked some questions about one of his other projects. This project was not met with the same level of success (see excerpt above). In this excerpt, Eric is describing a sprinkler system that he designed. But his level of connection, and the extent to which he takes ownership of the sprinkler system, differs greatly from how he felt about the alarm clock.

[05:42.7] Eric: So, umm, it, like, the sprinkler… So the idea was it wouldn't go on when it's dark, rainy, or cloudy becau < - > rainy or cloudy cuz it was there when it's moist and it doesn't need watering and then it'd be programmed to turn on when it was sunny and then for twenty minutes it would only for then.

[06:19.6] Interviewer: Okay.

[06:19.8] Eric: And it would just save, like, a bunch of water and money and stuff.

Instead of statements like 'I designed …' Eric used, 'the sprinkler system' and 'it.' In a few instances he does still use 'I' language, but these are utterances that would have been difficult to externalize. To be more concrete, consider that Eric's first excerpt consisted of 128 words, and 12 occurrences of the word 'I.' The extended version of the second excerpt, truncated here to conserve space, consisted of 169 words and contained only one occurrence of the word 'I.' Thus we see a contrast in how use of the word 'I' signals different levels of identification with a given entity, and varying depending of the success and sense of accomplishment of the project.

Using 'You' in Conjunction with System Language:

Looking at Table 1, one sees a number of individuals who used a combination of 'I', 'you' and 'the' statements. One hypothesis is that this was the students' attempt to emulate the academic discourse of someone who teaches or instructs. As individuals that are still entrenched in the education system, these students are likely to encounter several teachers who utilize "you-oriented" instructional statements like "first you take the bottom number and…" in order to adopt a more conversational teaching discourse. As such, this emulation of instructional discourse may be a demonstration of an increased mastery in a domain, or at least a self-perceived mastery (Worsley & Blikstein, 2011). More specifically, the use of 'you,' may be similar to the ways that experts describe ideas or devices for less, or equally, knowledgeable individuals. Given the amount of time the students spent on their projects, they may have begun to self-identify as experts about their own projects. Therefore, for them to take on this identity as an expert of their projects is quite telling of how their identity has changed in the process, even if only in this limited domain. To further explore this, we examine an excerpt from one of the students who is describing to the interviewer how they would design a piggy bank that automatically counts coin values.

[00:00:14:04] Francis: Okay. This is kind of cheating because one of the things my father got me for Christmas was a coin jar that does exactly that. What you do is have for the part where the coins go in, a little < ahh > lever that looks like that and depending on how far it's pushed down you could tell the size of the coin and therefore the value of it because all coins are different sizes. And then you can just record that with some software that is in GoGo because GoGo as far as I know can't display numbers like just tell it display number.

As an individual who used to own such a piggy bank, Francis feels like an authority on this topic, and projects that self-perceived authority in how he describes the system. For one listening to him speaking, one gets the idea that he is a teacher explaining this idea to a student.

By looking at the use of the verbal discourse associated with personal pronouns, neutral references, and neutral references combined with professorial language, we can identify the extent to which students identify with, or relate with, the subject matter that they are discussing. Even within the same interview, as was the case for Eric, one can use these cues to observe how the students related to the different projects that they worked on.

Identity in Conflict

Having looked at some of the identity cues that are triggered from an individual's specific language, we now look at a more macro-level analysis of how the different identities that someone has may be in conflict. More specifically, we present three case studies of individuals that show how conflicting identities can be indicative of a student's learning trajectory (Wenger, 1999; Yoder, 2000), and how the nature of the conflict dictates whether or not that individual is "in-bound" or "out-bound."

We begin by again looking at Eric. Reading his transcripts, one notes that he has a deep interest and excitement in engineering design. In fact, near the end of his interview, Eric states that his career goal is to be a Disney Imagineer. To this end, Eric is confident in his ability to do engineering design. However, a conflict arises when Eric realizes that he has not yet attained the level of expertise to be a practicing engineer. We see this develop in the following excerpt where Eric has just finished describing how to build his automatic piggy bank. The last question in this series challenged students to defeat their own system, i.e., to find a way to cheat the piggybank system that they had described just moments before.

[12:28.7] Eric: Hmmm…Anything cheat my own system… Nope I'm too good, they can't get past me.<laugh> I can't even get past my own system. So yea…

[12:41.9] Interviewer: Can you think of any other way?

[12:43.5] Eric: Ahhh, maybe… Is there supposed to be another way? Or…

When Eric asks "is there supposed to be another way?," he has been forced to come to grips with his own lack of knowledge concerning the question at hand. Heretofore he had maintained his confidence and answered all of the questions with resolution and conviction, save the occasional disclaimer that "he's not a good drawer." However, when this conflict happens, he is expressing frustration, and genuine uncertainty. Based on the work of Liscombe et al. (2005) and Forbes-Riley et al. (2009), we believe that this conflict between the level of confidence that Eric maintains and the uncertainty that he just expressed is a point that demonstrates his in-bound trajectory towards being an engineering-designer. He could have easily given up on the problem, and maintained that there was no way to cheat his system, but instead he momentarily puts aside his confidence, and his identity as a budding engineering-designer, to admit the need for help.

A similar conflict arises for Shannon. However, Shannon's conflict differs in that, while Eric had developed this identity of wanting to be a Disney Imagineer before coming to the workshop, Shannon did not have such aspirations and found empowerment in the workshop. We briefly look at the conflict that she faces while trying to design the automatic piggy bank and then return to our discussion.

[00:08:47.30] Shannon: That's OK. Um, you would have one slot with maybe…. Um, I don't know. It seems like it's a very common design, like on the vending machines and… like, there's one single slot. I was thinking that you'd have a lot of lasers, like, to see how large the coin you would put in would be…

[00:09:17.70] Interviewer: OK.

[00:09:18.40] Shannon: …but it seems like it would be a bit difficult. Then again I thought programming a Roomba would be difficult and it wasn't so… Mm…

To provide context for the last statement that she made, roughly a week before the interview, Shannon, along with her project group, sat down with one of the teaching assistants to brainstorm how to design and program a Roomba robot. At first, the three girls were quite perplexed as to how one would go about programming a Roomba. However, after working with the teaching assistant for about 15 minutes, the girls had not only figured out a set of behaviors that they could use to dictate the Roomba's movements, they had actually programmed the behavior and tested it out using a robotics kit. It is in reference to this experience that Shannon is referring. She is indicating that the experience of programming the Roomba was powerful for her, and it increased her confidence in her ability to do programming-related tasks. Having realized this newfound confidence, she was surprised by the difficulty that she was having in tackling a problem that she perceived to be difficult, yet solvable. Again, we see this conflict as being an indicator of change within the student, and a marker of her in-bound trajectory towards engineering design.

Finally, in the space of identity conflict that produces growth, we consider a quotation from Sadie. Sadie was a 9th grade student who initially seemed apprehensive about fabrication, and appeared to be more interested in the social aspects of the class than she was about digital fabrication. She encountered internal conflict during the exit interview and unintentionally hints at it.

[0:03:51.9] Interviewer: Could you write a program to make that, to do that?

[0:03:59.3] Sadie: Like, me? Or, like, anyone?

[0:04:00.9] Interviewer: Yeah, you.

[0:04:01.8] Sadie: Um, it would probably take me a few tries but I think I could.

In the above exchange the interviewer asks Sadie if she can write a program to control the temperature of a room given the appropriate sensors and actuators. Sadie responds by asking for clarification on if the interviewer means 'you' in general, or "you," as a specific reference to Sadie. What is interesting is that if Sadie was confident in her own ability to write the program, disambiguating the meaning of 'you' would have been irrelevant. If she could write the program then, the answer to the less constrained, general question of whether or not a program could be written would have also been positive. Instead, Sadie's question suggests that she is just now recognizing her identity as being someone who is able to write computer programs, and that this additional identity is in conflict with her previous conceptions of her own abilities. Even so, after some hesitation, she makes it clear that she has begun to identify herself as someone that can write computer programs. As such, her conflict and her response to that conflict, indicate that she is on an in-bound trajectory.

For Eric, Shannon and Sadie, the digital fabrication and invention course offered a space to become increasingly confident in their ability to design and build. In some cases this increase in confidence was greater than their actual increase in engineering design ability. Nonetheless, this appears to be an instance of social validation (Gee, 2001) in which one's identity only has meaning if it is validated by others. In the following case study we see an example of the opposite.

Kyle is a student who appeared to have received a lot of positive feedback in his traditional classes. In fact, during the start of the second month he shared with the entire class about how his teacher had selected his geometry project as one of the best he had ever seen. In the digital fabrication and invention environment, however, Kyle struggled. And instead of recognizing his struggles and trying to improve on problems that he experienced he typically chose to neglect them. We see this by examining a pair of excerpts from Kyle where he describes the tic-tac shooting gun that he designed with a colleague.

[00:00:03:11] Interviewer: Is this design < – > why did you use light sensors? Is it designed to catch

someone who is using a light or something or is it just a way to control it from a distance?

[00:00:03:24] Kyle: It's just a way to control it from a distance actually.

...

[00:00:04:59] Interviewer: I see. Cool. Did it work out as well as you wanted?

[00:00:05:03] Kyle: < Hmm > yeah, actually it did.

In the first exchange we see Kyle respond and conclude his statement with the word 'actually'. When listening to Kyle's statement, and the way that it's said, it's apparent that Kyle had not really thought through this part of the design, and was simply going along with the interviewer's suggestion. In this way, we would argue that the very inclusion of the word 'actually' at the end of the sentence is an overstatement suggesting that this *actually* wasn't their intention. And, in fact, the inclusion of the light sensors was largely motivated and partially implemented by one of the facilitators. To this end, the students may have merely included it to satisfy the facilitator, and may not have truly taken ownership of it. Beyond this, their description of its purpose seems to suggest that they had not truly considered the utility of adding this component.

In the latter exchange, we see this word 'actually' come up again. This time it is in the context of Kyle having any ideas for improving his gun. In this instance he attempts to resolutely state that there were no improvements that he wanted to make. Of course, this occurred after he pauses to think first, as indicated by the 'hmm'. Moreover this response is in direct contrast to how Kyle and his partner were then attempting to make modifications to the gun so that it would shoot farther. However, in both of these instances of conflict, Kyle attempts to maintain the identity of a strong confident student. We would argue that this demonstrated Kyle's outbound trajectory from this engineering design community. As a source of comparison, even students who constantly struggled to complete their projects, and were regularly reminded to get back on task, were willing to propose modifications or improvements to their system, but not Kyle. In the face of conflict, he decided to take the safe route.

Identity in Development

In addition to seeing how conflict impacts an individual's identity, and how we can characterize their trajectory, we also examine the ways that the student's identities are developed, and the impact that this has on them. We frame this discussion in terms of acquired identity and learned identity (Gee, 1999), where we are again focusing on the individual's identity as an engineering designer.

Acquired Identities

In only three of the interviews that we conducted did we find that the students were engaged in a community or peer group that fomented their appreciation of engineering design. Two of these three students described the interaction as being with their fathers. Francis describes a toy that his father got him as a resource that would allow him to "cheat" in solving the automatic piggy bank problem. And as we previously observed, this resource, and presumably other such devices, influenced Francis's identity as a builder.

However, simple exposure to a device in the home setting does not always facilitate becoming an expert with that device. This fact is suitably displayed by the experience of Violet. Like Francis, Violet had owned an automatic piggy bank as a child. However, Violet had no idea as to how it operated. There was a different culture in her home than the culture in Francis' home. This is partially characterized by the way that Violet talks about the piggy bank. Instead of attributing its ownership to a specific family member, as did Francis, Violet simply remarks that she used to have one. This is suggestive of her not having the resources to build a strong identity in terms of being an inventor, despite having the same device as a child.

To further emphasize the idea that it is the interactions that matter, consider the experience of Gunther. Gunther is another of the students that continued to work on his project after it ended. In two separate instances of his interview, he alludes to discussions with his dad and experiences that his dad had shared with him, that helped inform his understanding of classroom material. This is not unlike the argument that Gee (2003) makes against those that reference decontextualized language, in that this home language and experience gives Gunther better knowledge to learn complex concepts.

[0:06:58.9] Gunther: Because things, very unpredictable things happen like this < snaps fingers > or this < snaps fingers >. It's like, you know, two or three years ago I forgot what, my dad's a buyer for Men's Warehouse. And suddenly on the east coast it's really cold temperatures hit. Suddenly, you know, it was the beginning of summer. And, you know, they didn't have many large coats and stuff in the stock but they had to get them there. So things like that will change. You know, trends and stuff. So, I think that nature is still in charge and a bunch of things can happen that we won't even think of.

Here we see the student refer to his dad in order to provide an example of changing trends. This same student later says the following:

[0:09:14.5] Gunther: Um, Smoking is a past example and that kind of happened the same way. My dad was telling me, that kind of happened the same way the cell phone thing is happening. These studies would just kind of pop out, um, or not randomly so to speak, but they just kind of happened. And then over time that led to people realizing, oh, smoking is bad. So, you see, so, that's another example of a phenomenon.

Again, an interaction with his father offers him an easier entry into some of the phenomena that were studied during the engineering design class. In these three cases, therefore, we see diverse cases of the influence of families in identity formation. In the two examples, we saw how Francis and Violet, despite having owned the same object in their childhood, had very different experiences with it with diverse impact on their identity as builders. Gunther, along the same lines, had meaningful interactions with his father about a variety of natural and social phenomena, mentioned them in the interviews, and showed to be comfortable in the position of explaining scientific ideas.

Learned Identities

Other students, however, had to approach engineering design from the learned perspective. Even though they were able to draw on previous experiences, they still exhibited great difficulty in engineering design, because they had not been exposed to a culture of design at home. Thomas offers a glimpse of this in his interview while trying to come up with the design for a device that can automatically count money.

[0:14:13.8] Interviewer1: OK. Do you have any speculations as to how they do that?

[0:14:18.0 Thomas: How? I have no idea how earthly < ?? > matters of the money, other than maybe, like, um, like a grocery store, they have that laser scanning thing.

Thomas is unable to conceptualize a money sorting device, and generally has a hard time even approaching the problem. Even though he was extremely motivated by the course, because he was operating from a learned identity, he encountered additional challenges. that required additional intentionality. Through the course of the class, we learned that Thomas has not had the same access or support in building and tinkering as some of the other students. He faces a larger barrier to entry into the inventing community; and without the external culture that promotes an invention identity it is harder for him to continue beyond the scope of the classroom.

The students that were able to move beyond the classroom have access to resources that can help facilitate their inclusion in the inventing and building communities. Furthermore, for these select students, the inventor identity was part of their acquired culture; but for the majority of the students, it was merely a learned behavior that they were just then being exposed to.

Conclusion

This paper's primary contribution has been describing and presenting a framework that can be used for identifying meaningful changes in student's identity through spoken utterances. Additionally, using transcriptions of student utterances we have been able to exemplify how the dimensions of identity in language, identity in conflict, and identity in development are manifested through a constructionist learning experience. Furthermore, we have looked at some of the possible impacts that a laboratory-based constructionist learning environment can have on student identity formation, maintenance, and development, with a particular eye towards seeing how conflict can help identify students' STEM trajectories. As we continue to grow this exploration of the role of constructionist learning environments on student persistence in the engineering disciplines we will maintain a keen awareness of how student identity may be changing. Furthermore, we will begin to also analyze student language, identity conflict, and external factors that promote identity development, in the day-to-day laboratory dialogue. All of this will further our goal of developing automated techniques that will allow us to systematically validate the learning that takes place in constructionist learning environments in a way that privileges learning processes over learning outcomes.

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The Continuing Story of the Painless Trigonometry Projects: Eratosthenes' method and the Parthenon

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Abstract

In this paper we continue the on-going story of the Painless Trigonometry projects in Mexico that we have presented at the past two Eurologo/Constructionism conferences (Jiménez-Molotla et al., 2007; Jiménez-Molotla & Sacristán, 2010). These are long-term, interesting, constructionist projects were students become engaged and motivated, while they learn many mathematical topics in the official syllabus in a fun and meaningful way, but also have early access to other "powerful ideas" (Papert, 1980), that is, "advanced" mathematical concepts, such as trigonometry that usually are not considered for students of the age-groups we work with (12-14 years-old). The main project presented was inspired by the host country of Constructionism 2012: building a model of the Parthenon, and along the way, we also engaged in another Greek-related project: the measurement of the Earth using the method of Eratosthenes.

Keywords

Mathematics; Trigonometry; 3D geometry; school project; Logo

Introduction

At Eurologo 2007, we reported our first long-term "Painless trigonometry" project (Jiménez-Molotla et al., 2007), and then in Paris, we presented an evolution of the previous projects: the "Eiffel tower project", inspired by the host city for Constructionism 2010. In Paris, we were asked if, for the conference in Greece, we would call our next project "The Parthenon", in honour of the new host city, and so we started thinking about this. We have spent the last two years working on this idea. Along the way, we also had the opportunity to engage in another "Greek venture", when we participated in a project to measure the Earth's radius using the method of Eratosthenes. Thus, in this paper, we present this year's work, which, appropriately for this conference, includes the work of two great Greek mathematicians, Pythagoras and Eratosthenes, as well as the construction of a model of the iconic Greek Parthenon.

Background and theoretical framework

As presented in our previous papers (Jiménez-Molotla et al., 2007; Jiménez-Molotla & Sacristán, 2010), in 2001-2002, the junior secondary school where Jesús (co-author of this paper) and his colleague Alessio teach, incorporated the Mexican, government-sponsored "Teaching Mathematics with Technology" (EMAT) program. That program promoted a constructivist use of open software tools ('open' in the sense of changeable; 'tools' in the sense that they help accomplish educationally relevant tasks – di Sessa, 1997) and therefore wanted students to be in control and have decision power on how to use the software; the tools in EMAT thus included

Spreadsheets (Excel), Dynamic Geometry (Cabri-Géomètre), and Logo (MSWLogo). That program provided the foundation for the future work in that school, in technology-based mathematical activities and projects: since around 2005, Jesús has worked in developing interesting constructionist (Harel & Papert, 1991) long-term mathematical projects with an integral use of technological tools like EMAT's Logo, Cabri and Excel, but also with other creative and expressive software. He has used these, not only as a fun and meaningful approach to many mathematical topics in the official syllabus, but also to introduce more "advanced" mathematical concepts.

As we explained in Jiménez-Molotla & Sacristán (2010), in the academic year 2005-06, Jesús and Alessio began a technology-based approach for the learning of trigonometry: the "Painless Trigonometry" long-term school project. In the first two academic years (2005-2006 and 2006-2007), approximately 250, 12-14 yr-old students, in grades 1 and 2 in two schools, were introduced to the Pythagorean theorem, basic trigonometry concepts and functions, and their applications using explorations and constructive activities with Cabri, Excel and Logo. At Eurologo 2007, the results of that initial project were presented (Jiménez-Molotla et al., 2007).

Trigonometry is not a topic that is included in the curriculum for that school level and is traditionally difficult to teach and learn; we used technology-based activities and constructions to give early access to that topic and provide experiences and "powerful ideas" (Papert, 1980) that might develop useful intuitive ideas (diSessa, 2000) on which to build upon later. At the same time we could cover other mathematical topics included in the official curriculum, such as: addition, subtraction, multiplication and division; powers and square root of whole and rational numbers; algebra (including constants, variables and polynomials); and geometry.

When that first project began, we never imagined the journey it would lead us on, creating a foundation for further trigonometry-based projects, such as the "Looking for the fourth dimension" 2007-2008 project (see Jiménez-Molotla et al., 2009), which led us to incursion in 3D geometry and the construction of pyramids in Logo; and the "Eiffel tower project" in 2009-2010 (see Jiménez-Molotla & Sacristán, 2010), where students engaged in the computer construction of that monument, using trigonometric ideas, pyramids and prisms ,as building blocks. All of the final constructions were carried out with Logo, but several other tools are also used for analysing figures and mathematical ideas, including Dynamic Geometry, Google Sketchup and Excel.

We would like to comment here on the emphasis we place on Logo in our projects. We feel that every mathematics programme should have some programming (or, at the very least, constructionist) activities; in our case it has been with Logo. We have delved into trying out other programming tools such as Scratch, but we always return to Logo, despite, on occasions, being under pressure to drop it from representatives of the Ministry of Education, or other colleagues, who claim it is outdated. We rely on Logo because we have not found a better tool in terms of both accessibility and power, and, of course, underlying constructionist philosophy and potential. And its influence has made us develop more constructive activities with other tools. Moreover, as it is illustrated later in this paper, students greatly enjoy and appreciate working with Logo.

In fact, though Logo is a central tool for us, we also believe in the importance of using, in an integrated and complementary way, a variety of tools for learning, since we consider that each tool brings with it a different type of knowledge and constitutes a different epistemological domain (Balacheff & Sutherland, 1994), and in this way we can provide several approaches and modes of representation with which students can engage and interact, thus enriching their learning experience (Wilensky, 1991). That is why other tools, such as Cabri, Spreadsheets and Google Sketchup, are always used according to a particular situation.

All of the projects described here are long-term projects lasting most of the academic year. This gives the opportunity to articulate the projects with the academic requirements of the official curriculum; the technology-based activities are interspersed with regular mathematics lessons and paper-and-pencil activities, but in a way that allows for all of the academic activities to be integrated. Moreover, working long-term on these projects allows students time to assimilate and explore the mathematical and technical ideas, as well as time to work on their computer constructions and the problem-solving and analysis that those constructions require. However, it is worth noting that every year we work with different students, so there is no continuity from one project to the next; that is, though each project builds on ideas developed in previous ones, we start from scratch each year with new students.

The 2011-2012 projects

In the academic year 2010-2011, we had as aim for our students to construct a computer model of the Parthenon. As has happened every academic year, we began with new students, so these students had to become familiar with the computer tools, with programming, etc.; as well as with the pedagogical model – where they are in charge of, and collaborate on, the explorations and constructions, and where the teacher acts as a guide – (students are not accustomed to this). However, that year it took longer, so none of the students completed the construction of the Parthenon; only some 3D animations and partial Logo constructions were achieved.

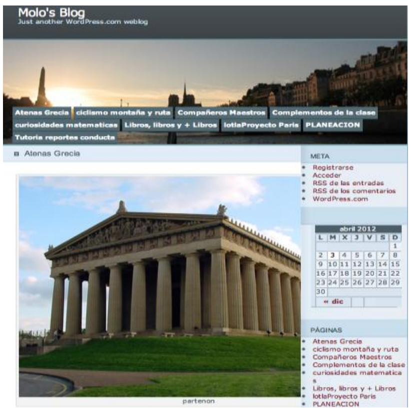


Figure 1. Cover page of the Parthenon project's blog

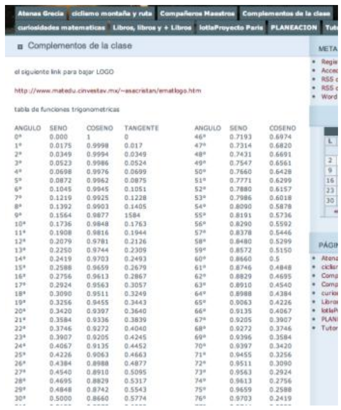


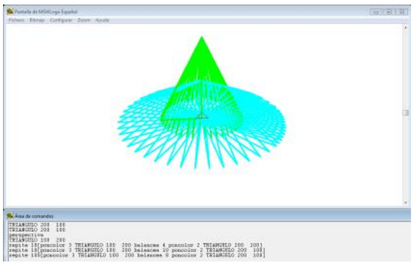
Figure 2. Resources on the blog: e.g. a link for downloading Logo and trigonometric table

This academic year, 2011-2012, there was an extra motivation to finish the constructions before the conference in Athens, so more time and effort was spent on the project. As has been done since the Paris project, a blog (Figure 1) was set up for structuring the project, for providing classroom resources (Figure 2) and as a place for students to upload and share their constructions and comments. As in all previous years, this project was carried out with all the groups in which Jesús teaches (several Junior Secondary Grade 1 and Grade 2 groups in two schools).

Groundwork: basic shapes, triangles, playing and animated 3D constructions

The activities began by learning to construct the basic shapes that would serve as foundations for later constructions. Dynamic geometry constructions with Cabri and Google Sketchup are used to create an understanding of the structural components and mathematical relationships, serving, as well, as a comparison and complement to the Logo productions, where the construction process and its relationships are carried out and expressed in very different ways. Spreadsheets are also used to organize the information and also to express the mathematical relationships. The interaction and complementarity of the constructions with the different software tools enriches the activity and understandings of the students and helps finish the project. It is worth noting that during each session, students are given some time to play with their constructions freely. Over the years we have found that students get more engaged with their constructions if they can play with them; it is an important motivating factor.

After the initial investigations with various software and basic programming activities with Logo, students are introduced to three dimensional work. Through this 3D work, students discover that geometrical bodies are constructed using basic geometric shapes, for example by rotating them (Figure 4). In order to work with 3D, we have found it invaluable to create a system of axis and cartesian planes to help with orientation; this work is thus an excellent way to introduce students in Grade 1 to negative and positive numbers, a topic from the curriculum that is normally presented in the month of February, but by doing this work, it can be presented several months earlier. Students also start trigonometric work: in Figure 4, students rotated a triangle that is constructed using the Pythagorean Theorem and the arctan function (see the corresponding MSWLogo procedure, which is the same one used in all the programs presented in this paper).



```
to triangle :x :y
fd :x bk :x
rt 90 fd :y
lt 180 rt arctan :x/:y
fd  sqrt(:x*:x  + :y*:y)
rt 90 - arctan :x/:y  lt :x
end
```

Figure 3. 3D construction using triangles, with Logo code

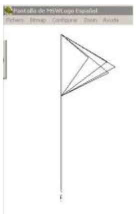


Figure 4. Animated rotating flag in 3D Logo

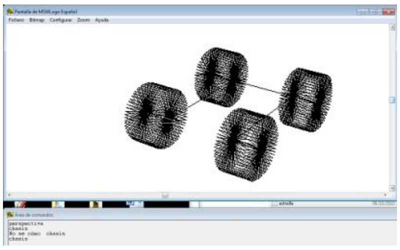


Figure 5. Animated car-wheels

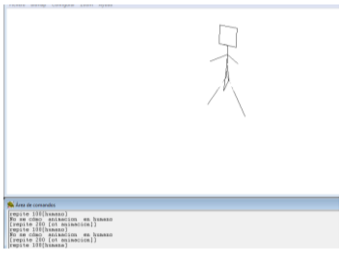


Figure 6. Animated human figure

Part of the 3D work includes learning to animate: 3D figures cannot be fully appreciated if seen from only one angle. One of the animation tasks that we've found particularly useful is rotating a flag (Figure 4). This year students also animated car wheels (Figure 5) and a person (Figure 6).

Measuring the Earth using Eratosthenes' method

Half-way through the academic year, we had the opportunity to participate in a project organized by the IFE-ENS Lyon, France, where a dozen school-groups from around the world measured the Earth's circumference and radius using the method of Eratosthenes, and shared their results in a video-conference on 16 December 2011 (see http://artsandstars.ens-lyon.fr/ArtsAndStars/ eratosthenes/20111216/ index). This was a very convenient addition to our painless trigonometry activities, where the knowledge that had been developed through the previous tasks and Logo constructions could be put into use. Moreover, this was also an opportunity to get involved in a cross-disciplinary project where students could use mathematics in real-life situations. Thus, one of the geography teachers was invited to collaborate in order to help students understand what had to be taken into account in the measurements; he gave information on the meridians and the Tropic of Cancer in order to explain how our position on Earth is located at a tangent to the Earth's radius. With this information, Google Sketchup was used to create an animation (Figure 7) of the Earth with its axes, meridians, etc.

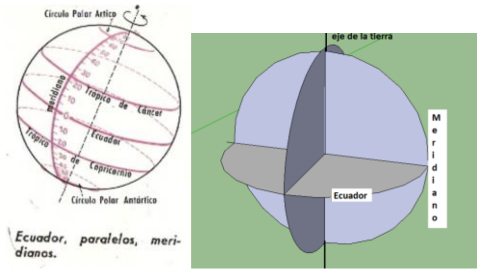
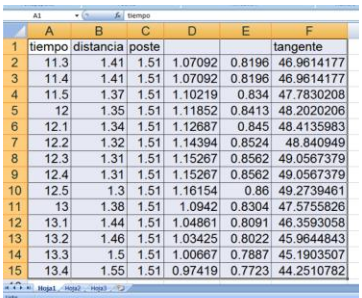


Figure 7. Meridians and tropics of the Earth (left) & animated model using Google Sketchup (right)

Figure 8. Measuring the angle between the sun rays and the vertical direction .

Figure 9. This team overlooked using the correct height for the pole.

Having had this insight, the next step was to use 1.5 meter-high poles as the tool (the gnomon) to measure, in the school courtyard (Figure 8), the length of the Sun´s shadow and determine the angle between the sunrays and the vertical direction (the solar zenith angle A) using the property that tan(A) = (length of shadow) / (height of gnomon). Teams of students were free to use any materials and carry out the measurements in the way they wanted; however, in one case, the task was so free that a team of students overlooked using the proper height for the pole (Figure 9).



	A	B	C	D	E	F
1	tiempo	distancia	poste			tangente
2	11.3	1.41	1.51	1.07092	0.8196	46.9614177
3	11.4	1.41	1.51	1.07092	0.8196	46.9614177
4	11.5	1.37	1.51	1.10219	0.834	47.7830208
5	12	1.35	1.51	1.11852	0.8413	48.2020206
6	12.1	1.34	1.51	1.12687	0.845	48.4135983
7	12.2	1.32	1.51	1.14394	0.8524	48.840949
8	12.3	1.31	1.51	1.15267	0.8562	49.0567379
9	12.4	1.31	1.51	1.15267	0.8562	49.0567379
10	12.5	1.3	1.51	1.16154	0.86	49.2739461
11	13	1.38	1.51	1.0942	0.8304	47.5755826
12	13.1	1.44	1.51	1.04861	0.8091	46.3593058
13	13.2	1.46	1.51	1.03425	0.8022	45.9644843
14	13.3	1.5	1.51	1.00667	0.7887	45.1903507
15	13.4	1.55	1.51	0.97419	0.7723	44.2510782

Figure 10. Collective record of the measurements.

Figure 11. Spreadsheet with collective measurements.

In December, 2011, ten days before the solstice, measurements were carried out every ten minutes, beginning at 11:10 in the morning, in order to determine the shortest shadow that would correspond to noon time. Each team recorded their measurement on the classroom's whiteboard (Figure 10) and all the students could use the collective measurements, also recorded in a spreadsheet (Figure 11) in order to calculate the tangents. The school in Mexico City was partnered with a school in Chile (therefore each was positioned in a different meridian) so that using both schools' measurements (the zenith angle found by each school), and the distance between the two positions, the Earth's circumference could be calculated. Participating in this project was highly motivating for the students. The results of all the participating schools can be viewed at http://artsandstars.ens-lyon.fr/ArtsAndStars/eratosthenes/ 20111216/2011-dec-solstice.

Building the Parthenon model

The Eratosthenes project was a nice way to put into practice some of the trigonometry learned on the journey to build the Parthenon model. Having the trigonometric and other necessary foundations, and thanks to the incursion into 3D constructions, work on the Parthenon could begin. Over several sessions, several attempts were made: First with Cabri, but the work was tedious and after several sessions of incomplete work (Figure 12), the students abandoned it. Models with Google SketchUp were much easier (Figure 13) but it was collectively decided that with Logo it was more interesting. One of the initial approaches was to build a rectangular base with superimposed circles that would form the columns. In Figure 14 and the accompanying code (translated from the original Spanish), one of the first attempts at building the Parthenon in Logo is shown. The student in this example avoided variables, but used multiple turtles, so that different turtles drew each column. It is worthwhile noting that in the EMAT version of MSWLogo that is used, the primitive *circle* has been deactivated so that students are forced to reflect on how to create their own procedure for this shape.

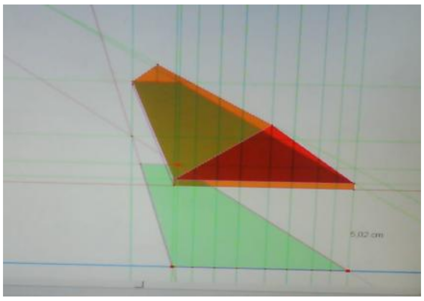


Figure 12. The furthest attempt to model the Parthenon with Cabri

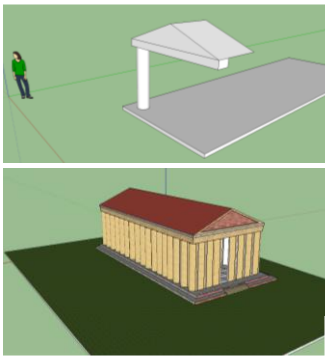


Figure 13. Modelling it with Google SketchUp

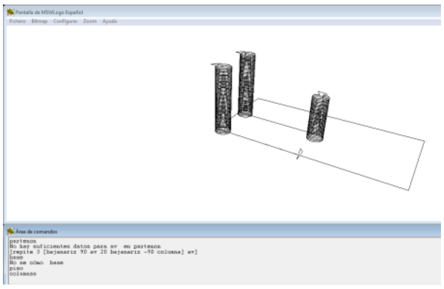


Figure 14. One of the first attempts towards modelling the Parthenon

```
to floor
setturtle 0
downpitch 90 rectangle downpitch -90
setturtle 1 downpitch 90 fd 100  downpitch -90
setturtle 2 downpitch 90 fd 100  rt 90 fd 200 downpitch -90
setturtle 3 downpitch 90 rt 90 fd 200   downpitch -90
end

to column0    <same code for: to column1, to column 2, to column3>
setturtle 0   <or correspondingly: setturtle 1, setturtle 2, setturtle 3>
downpitch  90
repeat 50[circle downpitch -90 fd 3  downpitch 90 circle]
end

to columns
column0 column1 column2 column3
end

to frontis
setturtle 4 fd 150 rightroll 90 rt 30 triangle
end

to rectangle
setturtle 0
repeat 2[fd 100 rt 360/4 fd 200 rt 360/4]

to circle
repeat 360 [fd .3 rt 1]
```

```
end                                              end
```

A following step was to build the roof (Figure 15), something that required trigonometry. It was also collectively decided that the best approach for the base of the Parthenon was to have a rectangular prism (instead of simply a rectangle) – see Figure 16Figure 15. Roof of the Parthenon . Below we show the Logo code created by a student, Carlos, for his Parthenon model (Figure 17).

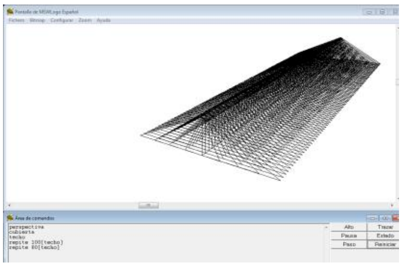


Figure 15. Roof of the Parthenon

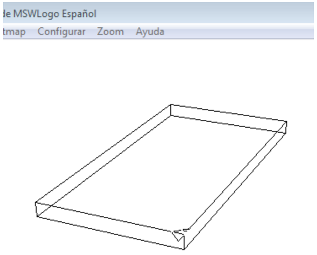


Figure 16. Base of the Parthenon

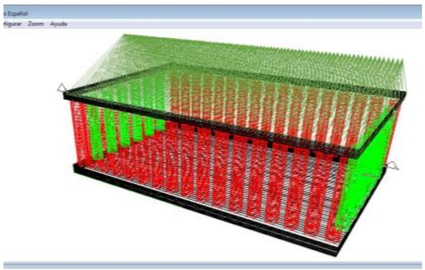


Figure 17. Carlos's model of the Parthenon

```
to partenon
base
setpencolor 20
fd 10 rt 90 fd 10
lt 90 downpitch -90
repeat 17 [ column1 downpitch 90 rt 90
penup fd 35.3 lt 90 downpitch -90]
downpitch 90 lt 90
fd 10 rt 90 fd 390
lt 90 fd 600 lt 90
fd 20 lt 90 fd 10 lt 90
downpitch -90
repeat 17 [ column1 downpitch 90 rt 90
   penup fd 35.3 lt 90 downpitch -90]
setturtle 1
penup
setpencolor 2
lt 90 fd 300 rt 90 fd 20
downpitch 90
fd 10 rt 90 fd 10 lt 90
repeat 6 [penup fd 50 pendown
   downpitch -90 column1 downpitch 90]
setturtle 2
penup
rt 90 fd 300 lt 90 fd 20
downpitch 90
fd 10 lt 90 fd 22
rt 90
repeat 6 [penup fd 50 pendown
   downpitch -90 column1 downpitch 90]
setturtle 4
lt 90 fd 300 rt 90 fd 20
penup fd 150 pendown
base0
setturtle 3
setpencolor 10
penup lt 90 fd 300 rt 90 fd 20
fd 150 downpitch 90 fd 200 rt 90
downpitch -90 fd 10 roofcover
end

to column1
repeat 50 [downpitch 90 circle 1 5
  downpitch -90 penup fd 3 pendown]
repeat 50 [downpitch 90 circle0 1 5
   downpitch -90 penup bk 3 pendown]
end

to base0
setpencolor 0
repeat 16 [downpitch 90 square 400 600
   downpitch -90 fd 1]
end

to circle :x :y
repeat 360 [fd :x rt :y]
end

to circle0 :x :y
repeat 360 [bk :x lt :y]
end

to square :x :y
repeat 4 [fd :x rt 90]
end

to roofcover
repeat 87 [roof downpitch 90 penup fd 7
   downpitch -90 pendown]
end

to base
setpencolor 0

to roof
triangle 100 200
```

```
downpitch 90
rt 90
penup bk 300
lt 90 pendown
repeat 20 [square 400 600 downpitch -90 fd 1 downpitch 90]
setpencolor 0
repeat 55 [fd 6 rt 90 fd 600 lt 90 fd 1 lt 90 fd 600 rt 90]
penup bk 400
fd 18 pendown
end
```

```
triangle 100 150
triangle 100 100
triangle 100 50
rightroll 180
triangle 100 200
triangle 100 150
triangle 100 100
triangle 100 50
rightroll 180
end
```

An important point here is that these constructions were built by the students themselves through a collaborative process over several months. Regardless of the approach, what matters is that the students achieved the goal. Here are some comments (translated from the original Spanish) that Carlos and other students made and posted on the project's blog:

Carlos: this was a great experience that motivated me …. It was a bit difficult, but I think we had a good result and I am very excited that it may get sent to Greece.

Ocaltzin: the Parthenon was a difficult challenge but very fulfilling, because to be able to build that marvel with a single program was so fulfilling. The most difficult part was when some instructions didn't come out as expected, then I had to look for what was the problem and fix it. But what drove me was to share this internationally, and that it would be something that would help me in the future. I liked very much how, through the [Logo] instructions given, it was a way to go over mathematics.

Emiliano: this Greek project was very interesting. Through Logo, we create the Parthenon using different formulas. I am very impressed with [its] value. Many schools in Mexico don't have Logo but we do… this project is very important … we [need to] take advantage of this opportunity because next year we may not have it… our teacher is the only one that does these things and uses [Logo] in our school. This project sometimes was difficult and most of the time not easy, but it's been fun and interesting.

Paulina: we have learned a lot about mathematics with Logo and the Greek Parthenon project was a bit complicated but in the end we could do it. I believe that this has been a great teaching that we have learned through the project, putting into practice our mathematical knowledge and creativity.

Eric: The Greek Parthenon project was a challenge, but for me Logo will help me in my career because I want to study to be a programmer.

Itzel: This project was very good, a bit hard but possible to achieve. It was a great experience to construct the Parthenon in Logo. I hope it gets accepted (:

Martin: Logo is a great software, very interesting. I've learned to do many things. I had trouble with many things and often I made mistakes before finishing, but as we progressed I liked it more and more and also got better. This has really been a challenge and its been an effort. I really appreciate learning this; it is the best software I've used…. Thank you!

Paola: I had learned Logo before [in primary school] but not well. Now … I've learned to use it and I like that … it is very interesting to do something interesting and exciting and every day something different. Logo helps do many things and can help [in the future] and is motivating for doing new things… The Greek project is very interesting, and also fun, that helps to know more things.

Andrea: What I've liked is that through Logo I am learning programming and I like that very much because it may help me with when I do my career, and also for works and projects in my school. And I think the Greek project is a homage to Greece and very important for Mexico.

Fany: Teacher, I want to tell you that I admire… how you make us understand, and how you work. I finally understand mathematics more or less. Thank you!

As we can see from all these transcripts, students agree that the project was a challenge and sometimes quite difficult, but they enjoyed this and are grateful. We also see how much they appreciate Logo. When students program through Logo, the graphic constructions are a result of doing mathematics: the construction of the Parthenon was a learning result in which mathematics were lived in a new way with hits and misses. As their interest in mathematics was awakened, it was also observed that their understanding of regular mathematical school work improved.

Challenges

Despite continuous reforms, there are little real changes in education in our country. Projects like the ones carried out by Jesús are much more appreciated abroad than in Mexico; similarly with programs based on constructionist or constructionism philosophies, such as the EMAT program, which (though appreciated locally) are no longer supported by the Federal government whose current focus is for developing competencies in the use of office software suites.

Jesús feels that Logo, in particular, is a means for uncovering the genius in children, some of who sometimes do not do so well in traditional school settings. This was the case of one boy who excelled in the "In search for the fourth dimension" painless trigonometry project that focused on the construction of 3D pyramids (Jiménez-Molotla et al., 2009): This student won several academic competitions, including one with the work done in our project, against university students who had won international contests in robotics; he even won a spelling contest; yet the school expelled him because he was too restless and they didn't know how to handle with him.

Also during the Eratosthenes' method tasks, some colleagues questioned why "waste time" on this; Jesús had to respond, using Asimov's (1972) words, that it is important for students to *rediscover what has already been discovered*. The Eurologo/Constructionism community has been an inspiration to continue the search on how to bring light and a new identity to education in our country.

Expansion of the projects, further research and concluding remark

All of the past projects in which we have been involved, have opened the possibility to expand further. A few years ago, Jesús could not believe that activities like these could be done with younger students; however, he has now been invited to collaborate with a small primary school, the Liceo "Robert Owen", in a village outside Mexico City. This is a school for which Jesús, who is an architect (besides being a mathematics teacher), had designed the building over 15 years ago (and he had done so in the shape of a castle with a tower "so that children can go up, be close to their dreams and be inspired"). Jesús had never had any experience with primary schools. But he is inspired by Richard Noss who once told him that "knowledge has no age; it is all about how it is taught". So he is now collaborating with the last two grades of that primary school, with some in-presence sessions, online and via video conferences. In his initial presentation to the school he told them that they would be like warriors defending Ancient Greece, inspired and motivated by the land of Pythagoras and Eratosthenes. The school, principal, teachers and children are so far highly motivated and excited about this incursion into digital technologies and Logo.

This is the kind of motivation that the Eurologo/Constructionism conferences have brought. In this case, the host city for this year's conference, not only inspired the Parthenon project described above, but has also inspired the way in which Jesús is now incursioning into primary schools, incorporating digital technologies in a way that is not just about using those technologies or perhaps new software that is in fashion, but rather as a means to construct meaningful learning. Because projects like the Parthenon one are not just about drawing a model, but rather are constructionist approaches.

On a separate note, we are now in the process of researching the long term impact of the participation of students in these projects. This has been challenging as it is difficult to track down students who have moved on to high-school and therefore are no longer readily available since the schools were we work do not go past Grade 3 (students aged 14-15) of middle-school. However, we have located a few of them and are interviewing them. We are interested in seeing how one school-year in the life of these students, of whom many claim, as seen in the transcripts above, that these experience would help in their future careers, has actually influenced their future learning and life.

It has been ten years in which Jesús and I have worked together. In those ten years we have seen the evolutions of these painless trigonometry projects and this year it was very fulfilling to be able to put to practice some of the trigonometry concepts developed in the projects for the measurement of the Earth. We look forward to further projects in this and other directions.

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Differential approximation of a cylindrical helix by secondary school students

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Abstract

Some of the findings of a research study referring to two third grade secondary school students' attempt to design the shortest path between two points on a cylindrical surface are presented in this paper. The students worked using a 3d Logo / Turtle Geometry environment (MaLT) which combined the dynamic manipulation of mathematical objects with the symbolic notation by means of the Logo programming language. The research findings showed that the microworld designed can form the basis for studying notions of the conceptual field of curvature in space at least at an intuitive level with the students developing meanings of notions such as curvature, torsion and isometry in space.

Keywords

Curvature, differential approximation, helix, shortest path

Introduction

One of the basic problems in geometry is to define those geometric objects which allow us to differentiate one geometric object from another or to know when these objects are the same. For example, line segments are defined according to their lengths and triangles through the knowledge of their sides (Congruent triangles postulate). Similar problems are proved to exist in the case of regular curves both in plane and in space in general. In particular, the curve is defined in an one and only way (apart from its position in space) by two functions of its arc length: curvature and torsion (Lipschutz, 1969). The notion of curvature is one of the central concepts of differential geometry; one could argue that it is the central one, distinguishing the geometrical core of the subject from those aspects that are analytic, algebraic, or topological (Osserman, 1990).

The notion of curve, the study of its properties and of the ways it can be approached consist one of the most important issues in third level education; as, for example, in differential geometry. The extremely difficult formalism as well as the complicated formulas required consist a significant obstacle so that these notions and differential geometry in general can become approachable to many a student. (Henderson, 1995; Kawski, 2003). Nevertheless, the notion of curve and notions related to it are met in 2nd level education syllabuses which, however, seem to focus on its various properties rather than on the notion of the nature of the curve as contrasted with straight line. For instance, they are met in polygonal approximations of curves, the measurement of the length of a circle and circular arcs, the measurement of the area of circular disc as well as in the study of the convexity of a function since the second derivative measures concavity, a curvature- type measurement. Similar approximating procedures can be applied in cases when, for example, the area and the volume of a cone are calculated. Curvature also plays an important role in physics. The magnitude of a force requires to move an object at constant speed along a curved path is according to Newton's laws, a constant multiple of the curvature of the trajectory.

The appearance of dynamic digital environments and especially of 3D spatial environments seems to make the scenery change. The ability to scrutinize and the dynamic manipulation digital technology provides nowadays can a) firstly, enable students to acquire experiences in such abstract notions generally in space, at least at an intuitive level before they reach the complicated formulas of differential geometry b) secondly, intervene in the transition from the intuitive level to the theoretical level (Jones 2000) c) thirdly, enable us to restructure domains (Wilensky, 2010). Especially through the use of the turtle geometry and its graphics we are given the ability to approach curves in an alternative and broader way.

The turtle approach enables us to turn to the real geometrical definition of the curves and develop representations which are often clearer and closer to the authentic definition (Loethe, 1992). According to Yerushalmy, M and Schwartz, J.L (1999), students by means of suitable digital tools engaged themselves in the study of a number of notions facing the problem of the study of the curvature of a level function reaching a high level of abstraction and an even deeper level of understanding. Researches have also shown that even young students can develop meanings such as curvature in plane when they engage themselves in suitable computational environments which combine the logo programming language and the dynamic manipulation of geometric objects. (e.g Kynigos and Psycharis, 2003).

In the unit below we are presenting the basic elements of the method we have implemented in order to approach notions of the conceptual field of curvature in space which is based on notions which can be met in any book of differential geometry (e.g Aleksandrov, et al, 1969; O' Neil, 1997). Then we 'interpret' the way of designing a curve in space through turtle movements.

The 'Local Turning and Twisting' method (LTT)

A curve in space can be regarded as the path of a moving particle and can be defined by the Frenet-Serret frame movement which consists one of the most important tools in order to analyses a curve in differential geometry. The Frenet-Serret frame {T,N,B}, where T is the unit tangent vector, N is the principal normal vector and B is the binormal vector, provides a local orthonormal coordinate system at each of its point. The T and N vectors define a plane which called osculating plane of the curve at this point. The role of osculating plane is similar of that of the tangent that is for an area very close to a point the osculating plane is that plane situated close to the curve than any other. The place of the osculating plane changes from point to point along the curve. Obviously, if the osculating plane does not change, we have a level curve and it coincides with the osculating. The rotation of the frame as it moves is given by curvature and torsion. Exactly as the rate of change of direction of the tangent is characterized by curvature, so is the rate of change of direction of the osculating plane characterized by the curve torsion. Below we refer to the strict definition of curvature and torsion more analytically so that the approximation we are going to implement by means of the turtle geometry is more understandable.

Let A and M be two points of a curve close to each other with arc length $\Delta\chi$. Let $\Delta\varphi$ be the angle between the tangents at these points. The average range of change of direction will be $\Delta\varphi/\Delta\chi$. Then the limit of the ratio $\Delta\varphi/\Delta\chi$ is defined as the curvature of the curve at the point A. Thus, the curvature is defined by the formula:

$$\kappa = \lim_{\Delta\chi \to 0} \frac{\Delta\varphi}{\Delta\chi}, (1)$$

The tangent has an important geometric property: near the point of tangency the curve departs less from this straight line than from any other. So, the distance from the points of the curve to the tangent is small in comparison with their distance from the point of tangency. Consequently, a small segment of the curve can be replaced by a corresponding segment of the tangent with an error that is small in comparison to the length of the segment.

In addition, it is known (differential of a function) that when Δχ becomes small enough the numerator of the quotient of formula (1) become almost equal to the product k*Δχ. So, we can by approximation claim that a Δχ small arc of a curve can be replaced by its tangent and the angle between the tangents at two successive points is given by the formula:Δφ=κ*Δχ, where κ is the curvature at this point. Proportional things apply to torsion but now Δφ is the angle between the osculating planes at neighboring points and it is proven that torsion measures the rotation of the osculating plane round the tangents.

By now using the metaphor of the turtle, the plane the turtle is on each time reflects the osculating plane of the F-S frame and the straight movement of the turtle consists the direction of the tangent of the curve. Let A and B be two successive positions of the curve for front movement Δχ. We can assume that the turtle at its initial position has the direction of the tangent at that point. In order this part to consist by approximation part of the curve we want the turtle to cover, the commands we are going to give to it have to reflect the movements of the F-S frame at two successive points which movements, according to the fundamental theorem of Differential Geometry, are defined by curvature κ and torsion τ. That is, the turning of its straight movement Δφ degrees on its plane determines curvature and the rotation round the straight line of its movement determines torsion. So the F-S frame movements are equivalent to the following movements of the turtle:

- Twisting around its direction of movement, that is : lr(:κ*:Δx)
- Turning in its plane, that is: lt(:τ*:Δx) and
- Moving forward Δχ, that is: fd(:Δx)

In addition, through the ability we are given by the software we are using to dynamically change Δχ we can have the desirable approximation by means of the tangents of the curve. If we combine the aforementioned with the Logo language commands, such as repeat or make or a simple recursion, we can have the graphic representation of any normal curve in space with satisfactory precision.

For a second alternative approximation we can by integration precisely calculate the angles where the turtle has to turn for a ‘local turning and twisting’ since curvature and torsion are rates of change. For example, it is proven that a conical helix has a curvature and torsion which are functions of the length of the arc by the formulas: κ=400/s, τ=40/s. By integrating, we are given the angles for a ‘local turning and twisting’:

$$\varphi = 40 * \ln\left(\frac{s+\Delta\chi}{s}\right) and, \theta = 400 * \ln\left(\frac{s+\Delta\chi}{s}\right)$$

The theoretical frame

Vergnaud (1988), introduced the notion of conceptual field as a set of situations the mastering of which requires mastery of several concepts of different natures. He claims that “a single concept does not refer to only one type of situation, and a single situation cannot be analyzed with only one concept” (p. 141), and he argues that teachers and researchers should study conceptual fields rather than isolated concepts. Thus, on the basis of the aforementioned it is meaningless to study, in the frame we are referring, the notion of the shortest path between two points on the surface of the cylinder on its own. We assume that the aforementioned notion belongs to the conceptual field of ‘curvature in space’ as the notions, for example, of rate of change and arc length which are involved in the procedure of designing a curve based on the polygonal approximation by means of its tangents, are directly related to the notions of curvature and torsion in space.

With our basic aim being to examine the meanings the students develop in relation with the notions of differential geometry we planned activities based on the learning theory through constructions (constructionism, Kafai and Resnick, 1996). A main characteristic of the method which we considered to be suitable in this particular case was to provide them with a half-baked microworld to start with (Kynigos, 2007) under the name of the ‘shortest path’. A half-baked microworld is software designed in such a way that it challenges both teachers and students to decompose them, change or even construct something with them. They do not consist ready environments to be comprehended by teachers and then be used by students. They incorporate various notions and offer the students the basis to interact with the microworld. They aim to serve as starting points and the user to be acquainted with the ideas hidden behind the procedure of their construction.

The computational environment

The computational environment we used in our present research is MaLT (Kynigos, C. & Latsi, M. 2007), (http://etl.uoa.gr) which integrates symbolic notation- by means of Logo programming language- and the dynamic manipulation of mathematical objects. It is an expansion of the turtle geometry of the ‘Turtleworlds’ in 3d geometric space suitable for the construction and exploration of geometric objects. The turtle movements are determined by following commands: fd(:n) and bk(:n) which command the turtle to take steps forwards or backwards, lt(:n) and rt(:n) move the turtle n degrees to the left or the right in its plane (osculating plane), dp(:n) and up(:n) turn the turtle upwards or downwards and rr(:n) , lr(:n) move the turtle around its axis. The basic tools of MaLT are (figure 1) the uni-dimensional variation tool (1DVT) which enables the user to dynamically manipulate the values of variables in a represented object and the 2d variation tool which is a two dimensional orthonormal system and is used to determine the co-variation of the values of two variables. An additional characteristic is its 3d Camera Controller which gives students the ability to dynamically manipulate the camera by means of the active vector and observes the object in the simulated 3d space from any side and direction he/she wishes. We should also point out the ability the user has got to insert ready-made 3d objects, such as a sphere or a cylinder, in a 3d virtual space and dynamically manipulate them.

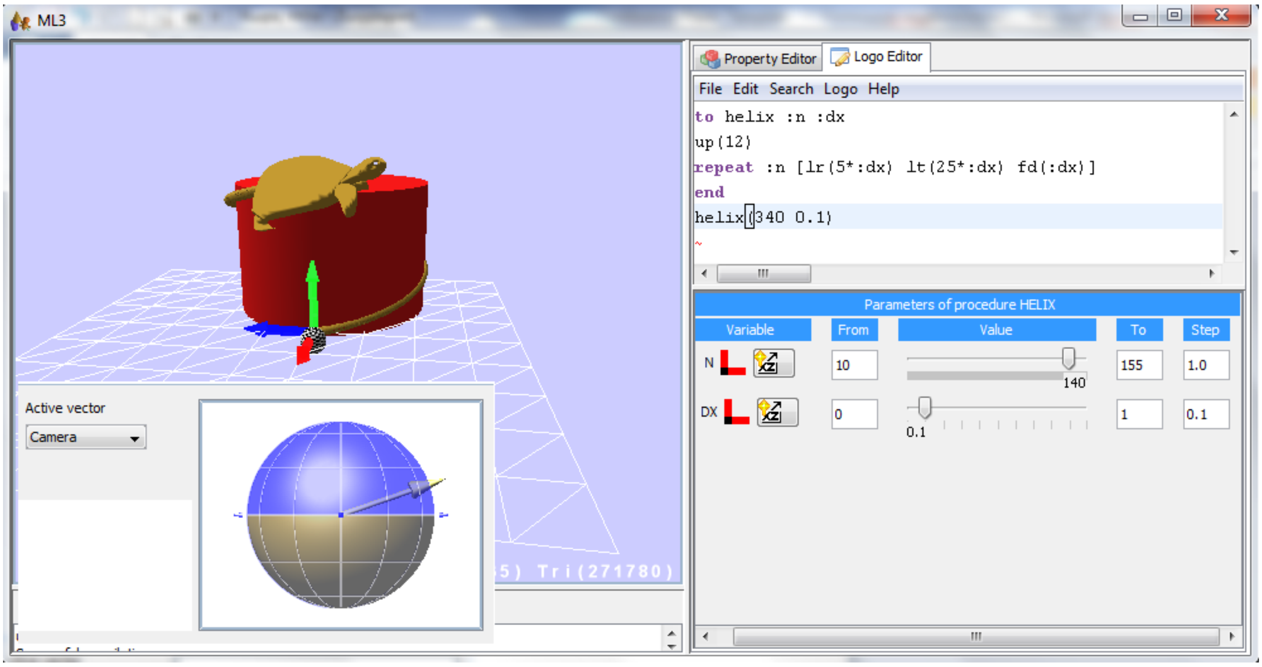

Figure 1: The environment of MaLT

The Problem

The students were given the following problem:

‘Calculate and design the shortest path between two points on a cylindrical surface’.

The students were told that they were allowed to use any materials they liked (for example, paper and scissors) and the following half-baked microworld under the name the ‘shortest path’:

to shortestpath :n :s :dx :c

repeat :n [lr(:s) lt(:c) fd(:dx)]

end

The aforementioned microworld comprises a program with four variables each of which express the following: n expresses a number of repetitions, s expresses the turning of the turtle around the directions of its path (it defines torsion), dx defining the length of the turtle step and c defining the turning of the turtle in its plane (osculating plane) which in turn defines curvature. The execution of the aforementioned code produces a polygonal line (either in space or in plane, Figure 2) or a straight line. But in the case when dx is considered to be too small (it tends to zero) three kinds of curves can result from the aforementioned microworld which virtually represent the geodesic of the cylinder.

For s=0 and c=0 line segments

For s=0 and $c \neq 0$, circles arcs

For $s \neq 0$ και $c \neq 0$, helixes.

Our students were informed that this program would enable them to work out the way they could design such a path and that, at the end, they themselves could use it in order to construct their own models.

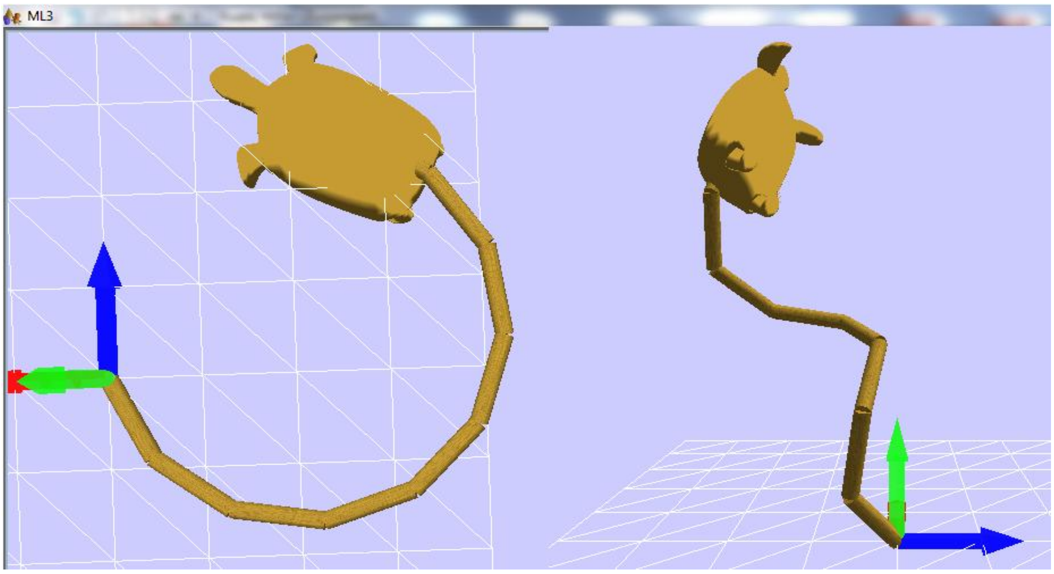

Figure 2: Polygonal lines both in plane and in space

The Method

The present research is a design-based research method (Cob et all., 2003), which consists part of a broader research, with the participation of two 3rd grade secondary school students and which lasted 19 hours. These particular students had already been familiarized with constructions in the logo programming language in the turtleworld environment. A video camera was used to record data and a sound and picture software (HyperCam 2) enabled the researcher to record the students' actions and the conversations amongst the participants. In order to analyze the students' mathematical thinking we were interested in the ways the students interacted with the available components of the software and in the ways they constructed mathematical meanings. At this point, we regarded the theory of situated abstractions, which enabled us to describe how the students construct mathematical meanings based on the functions of the particular software they were using and on the conversations between them, as extremely useful (situated abstractions, Noss & Hoyles, 1996). Another point we also focused on was how the students were trying to change the functionalities of the 'faulty' microworld they were given aiming to produce a different artefact which automatically give a helix with the shortest length (instrumentalization, Guin and Trouche, 1999).

The results

The role of tangible tools

Although the students at first turned to the software they had been given in their effort to give an answer, they soon realized something else should be done. They decided to use the tangible objects, that is the paper the pen and the scissors, they had also been given. By rolling the paper up into a cylinder, they came to the conclusion that it would be enough to assume two points on the cylinder which would belong to the same generator and would be on the cylinder bases. The designing of a line which would join them (apart from the straight line) would be the solution. Upon unrolling the cylinder they noticed that the line which was formed would be a straight line on the plane (geodesic in plane) but when they re–rolled up the cylinder a helix was formed.

Nevertheless, this conclusion, although it seemed to be the solution, did not seem to satisfy the students at all.

S1: If we could suppose that the cylinder opens, then okay it is a straight line

S2: But if the cylinder could not open? (Meaning: then how could we design the helix?)

The conclusion the students came to through the above experimentations is that the curve in demand is a helix. The designing of such a curve though without the use of tangible materials, and the ability to generalize such a procedure demand the use of differential geometry notions which reflect the Frenet-Serret frame movement in space. The students appear to realize the limitations of tangible materials, and the inability to generalize the procedure in situations when their use is impossible.

Finding the way to design the helix by using the turtle

The aforementioned students' speculation stimulated the researcher to impel them to use the software and the half–based microworld they had already had at their disposal. The students chose to insert a cylinder –out of the ready-made objects -of a 2.1 radius and a 5.54 height and by using the variation tools they tried to achieve the construction of a helical line which twisted round the cylinder with its two ends being the ends of the generator of the cylinder. Their initial suppositions referred to values which, although they seemed to have achieved their goal (that is the helical line to twist round the cylinder), the use of the camera proved wrong. Thus, from that time on each and every attempt of theirs initially comprised finding the values for n, c and dx with the simultaneous use of the camera and change of the values of the variables.

At their first correct attempts (with dx=1), they came to the following values: n=14, c=25, s=5 and dx=1. Although they seemed to be satisfied with the result of their experimentations, they continued to experiment after the following questions on the researcher's part:

R*: Is this a helix? (They play with the camera, zooming in on the screen at the same time)*

S1: They look like lots of straight lines (they are referring to the line segments which the helical line is composed of and with the execution of the half –based microworld provides them with)

R: What can you do so that you can turn it into a helix?

S1: Eliminate the angles

R: How can you eliminate the angles?

S1: If we decrease dx, let's say to 0.1

S2: If we multiply it by ten [and then in the application he divides it by ten]

But the execution of the code with dx decreased demands a simultaneous change of the values of the other variables, c and s. And that is because, by changing dx and replacing it with a smaller value, a helical line is produced but it is not in accord with what they are expecting. This mainly occurs due to the following reasons: Firstly, the helical line does not twist round the cylinder they had inserted (the initial position of the turtle plays a significant role here but at the same time the values of c and s are such that at least graphically do not affect it) and secondly, it does not produce the shortest path (since if dx is replaced by a smaller value, a line of a shorter length is produced). After they have put down the values in their worksheets, they come to the conclusion that as dx takes smaller and smaller values we are given a line which looks like a helix with a length constantly decreasing and that the ratios c/dx and s/dx remain invariant and equal to 25 and 5 respectively. In fact, the rate of change of directions of the segments the turtle is moving on (the tangent) and its plane (the osculating plane) which define the curvature and the torsion of the curve respectively remain invariant. The replacement of the ratios they discovered in their initial code provides them with the corrected code and the solution in demand as it shows in figure 1:

```
to shortestpath :n :dx
repeat :n [lr(5*(:dx))  lt(25*(:dx))  fd(:dx)]
end
```

Then the researcher asks them:

R: Which values provide us with the helix we are looking for?

S1: The smaller dx is the better.

The student seems to realize that the solution they are looking for does not only consist of the above code for specific values of the variables but it should also combine a limited procedure for dx. In fact, this procedure produces the correct helix only when $dx \to 0$.

3D Reflection about a plane

After the students had successfully designed the shortest path, the researcher asked them if there were more helixes to the same cylinder which get again gave the shortest path between the two points. The students started to experiment using the variations tools and the camera and by now examining a variety of combinations of values, both positive and negative, they came to various conclusions which were related to the notions of isometry and orientation in space. The case when the students 'came across' the notion of isometry is characteristic. Whereas they had a helical line with values c=3 and s=0.06 their experimentation with the aid of the variation tools led them to the values c=3 and s=-0.06 which virtually gave them a symmetrical helical line for the xz plane. It is a reflection about xz plane, and the two curves twist in opposite ways (if the first is 'right- handed', then the second is 'left-handed') since both helixes have the same curvature and opposite torsion (a fundamental theorem of differential geometry).

R: These figures (he means the one where c=3 , s=0.06 and the other one where c=3 and s=-0.06) are different? If so, what are they different in?

S1: Substantially, they are exactly the same helixes. They are identical but they have the opposite direction

S2: It looks as if we had a helix which reflects in the water

Conclusions

The purpose of the present research was dual: Firstly, to study the degree to which this particular microworld could form the basis for the study of notions of the conceptual field of curvature in space by young, second level education students and secondly, to study the meanings developed by these particular students in their attempt to design the shortest path between two points on a cylindrical surface. The computational environment used in this research along with the LTT method helped students to express mathematical meanings for a number of notions of differential calculus (for example, rate of change) as well as of differential geometry (for instance: curvature, torsion, geodesic and isometry) which has been shown to be notions difficult to be approached by even math students. One of the major advantages of the method applied is the fact that, not only were students able to visualize the Frenet–Serret frame movements (the role of which was replaced by the turtle) but the students were also given the ability to study, explore and symbolically represent these movements (by means of Logo) which are not easily achieved in dynamic geometry environments (DGEs). In this way, even young students are given the ability to engage themselves in notions of the conceptual field of curvature in space, at least at an intuitive level, before they reach notions of differential calculus and the complicated formulas of differential geometry. Although the way they used to design the helix does not tally with the strict formalism of differential geometry, the answers the students came up with are indicative of the fact that a restructuration (Wilensky, 2010) of the notion of curve based on its polygonal approximation is feasible in secondary education.

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Nicodemus explores Egyptian fractions: A case study

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Abstract

In this paper a fifth grader is involved in interplay with a computational environment trying to construct algorithms relevant to Egyptian fractions. More specifically, the student worked in the Balance environment which is a software aiming to help teaching and learning of rational numbers. In the context of this study the student was trying to find algorithms for expressing any unit fraction as sum of other unit fractions. This environment supported the student's experimentation and gradually he altered the initial interface of the Balance by adding or substituting components reaching thus a final version that could be regarded as an instance of an artefact that mirrored his own constructed knowledge.

Keywords

Egyptian fractions, Balance software, constructing algorithms, primary education

Introduction

Two aspects relevant to the issue of construction of knowledge are examined in the theory of constructionism. First, students learn by actively constructing new knowledge rather than by having the knowledge officially provided to them (i.e., constructivism). Second, what is taking place is learning-by-making, which means that effective learning takes place when the student constructs personally meaningful artifacts (Harel & Papert, 1991). The artifacts themselves constitute expressions of mathematical meaning and at the same time students continually express meanings by modulating them. In this spirit, the attempts of a fifth grader to construct algorithms—ways for writing any unit fraction as the sum of other unit fractions in the environment of *Balance* (a computer interactive program)— are examined. Thus, in a broad sense, the final product of the student's interaction with the program that would describe the asked algorithm could be considered as an instance of constructionism. A keyword in this process of reaching the algorithm will be 'experimentation'. Papadopoulos and Iatridou (2010) describe the systematic approaches of two 10th graders who use experimentation to explore mathematical relationships, make and check conjectures and generalizations. They emphasized the importance of experimentation as an innate factor of successful problem solving. However, in this study a much younger student, a 5th grader, is experimenting in a computational environment in order to discover algorithms concerning Egyptian fractions. More specifically, instead of presenting the algorithms to the student, the student himself interacts with the program, changes continually the given situation by adding or/and substituting components and ends with a situation that actually describes visually the algorithm.

The mathematical topic.....

It is known that Egyptians used fractions. More specifically, with the exceptions of 2/3 and 3/4, all of their fractions were unit fractions (i.e., fractions where the numerator is one and

denominator any whole number). Thus, any fraction with a numerator larger than one had to be written as the sum of unit fractions. In order to carry out computations with unit fractions the Egyptians used to use tables. For example, they created a table of expansions of the numbers 2/n for all odd numbers n<100 showing the combination of unit fractions resulting from doubling unit fractions: 2/n=1/n+1/n. There is no unique way to write a fraction as a sum of unit fractions (Clawson, 1994). However, in this paper we are interested in algorithms for writing a unit fraction as a sum of unit fractions. According to Eggleton (1998) there is a unique answer to the question: 'In how many ways can 1/n be expressed as the sum of two positive unit fractions?'. If we consider d the number of positive integers that divide n^2 and ignore order in the representations then it can be proved that the answer is (d+1)/2 ways.
Numerous papers had examined the way fractions are conceived by students and had recorded relevant difficulties, misconceptions and errors. A full presentation of the research findings is beyond the scope of this paper. An important part of the existing literature describes the work done in a computational environment. Technology can provide an alternative to rote learning and automatic memorization since it can support students by allowing the construction of definitions and algorithms by students (Yerushalmy, 1997). So, we are asking for computer tools different from the drill and practice or tutorial software that are prevalent in many elementary schools. For example, Olive (2000) presents the TIMA that was developed in the context of a constructive teaching experiment focused on children's construction of fractions.

...the *Balance* program.....

The *Balance* is an interactive software that was designed in the context of *Enciclomedia*, a national project in Mexico. Its main purpose was to help in teaching and learning of rational numbers. It functioned as a space in which students and teachers could explore their ideas about rational numbers by working with activities involving equivalent fractions. The users can create balances with different numbers of weights and on different levels. On each weight, natural numbers, fractions and decimal numbers can be written. The program indicates, in real time, visually and with sounds, where the balance is in equilibrium or not, according to the values which are assigned to the scales. Working with teachers, Trigueros and Garcia (2005) found that the *Balance* can help teachers to reconsider their strategies and to understand the purpose of the activities included in the official textbooks relevant to equivalence of fractions. Working with students, Lozano and Trigueros (2007) found that the tool helped the students in their learning of the concepts related to fractions. More specifically, they found that the students gradually modified their actions from trial and error to finding systematic methods to solve the problems which included the use of operations with fractions and comparison of fractions using the concept of equivalence. Additionally, it seems that during this interaction between students and software mathematical learning occurs and this can be partly attributed: (a) to the fact that the program gives immediate and useful feedback inviting students to reflect on their own answers and to the fact that the students are provided with freedom to explore different situations, and (b) to experiment with different strategies (Sandoval, Lozano & Trigueros, 2006).
In this paper we try to broaden the usage of this software by asking students to construct an algorithm. Actually, the students are asked to proceed in an unorthodox way compared to the one they are accustomed. In the classroom usually a valid statement is presented and the students are asked to accept it and develop the relevant skill by working on a sufficient number of exercises. But, in this work, the wording of the statement (i.e., there are certain algorithms for writing a unit fraction as sum of unit fractions) is rather presented as a problem and the student's final step will be to invent these algorithms.

Description of the study

Nicodemus is a 5th grader in a primary school in Thessaloniki, Greece. He has been taught during the regular schooling basic facts about fractions: comparison, equivalence, operations. For the purpose of the study a web based flash version of *Balance* was used available at http://recursos.encicloabierta.org/enciclomedia/matematicas/enc_mat_balanza/ . Nicodemus was asked to find if possible at least two ways for writing a unit fraction as sum of unit fractions. Capturing software was used (CamStudio-Recorder) to record in a movie format anything happening on the computer screen. The student spent enough time to be familiar with the software before proceeding to the main activity that lasted one class-period. The student was asked to vocalize his thoughts while performing the task and the session was tape-recorded. Then the data were transcribed for the purpose of this paper. The movie and the transcribed protocol were examined in order to find out how the student's interaction with the tool can result to the creation of an instance of the tool that will support him to establish the asked algorithm.

The wording of the task was: "Use the *Balance* to find out at least two different ways for writing any unit fraction as sum of other unit fractions". Implicitly, the task highlights another important issue in mathematics teaching in relation to constructivism. While very often the support for constructivism comes from observations of situations where new knowledge has arisen from concrete situations, it is also necessary for constructivism to account for the more complex mathematics formed by the processes of abstraction and generalizations of earlier ideas (Booker, 1992). Thus, in the specific task it was expected that two algorithms could be found via the usage of the software: First, the pretty much obvious algorithm of writing each unit fractions as sum of its two halves: $\frac{1}{n} = \frac{1}{2n} + \frac{1}{2n}$. Second and more complicated was the splitting algorithm based on the equality $\frac{1}{n} = \frac{1}{n+1} + \frac{1}{n(n+1)}$. In terms of elementary mathematics this could be explained by the usage of equivalent fractions:

$$\frac{1}{n} = \frac{n+1}{n(n+1)} = \frac{n}{n(n+1)} + \frac{1}{n(n+1)} = \frac{1}{n+1} + \frac{1}{n(n+1)}$$

Results and Discussion

The examination of the student's attempts to construct the algorithms allowed us to split the whole process into distinct episodes.

Episode One: First Algorithm

Nicodemus found it very easy to set-up the first algorithm. It was not necessary for him to use the *Balance* as a vehicle to find the algorithm.

N1: I can use halves. For example if I have ½ then I can write it as the sum of its two halves 1/2=1/4+1/4.

He used the *Balance* only to verify his first algorithm (Figure 1).

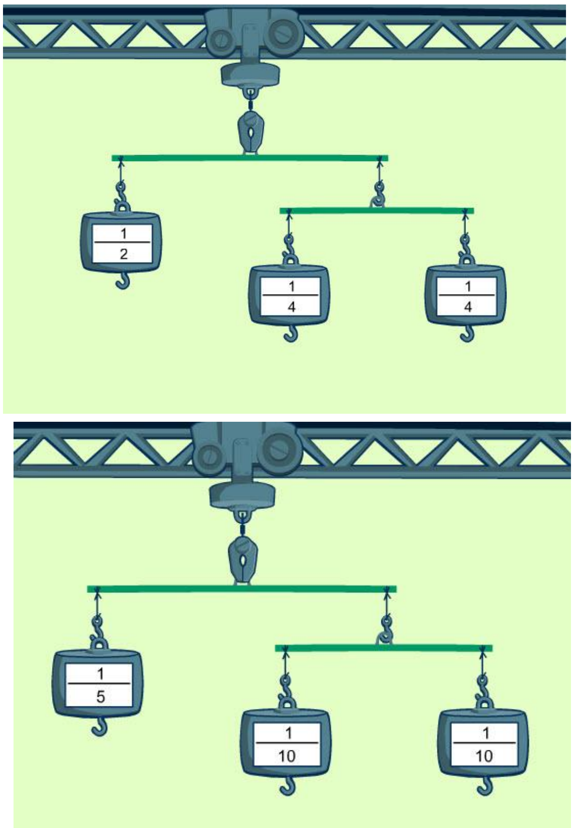

Figure 1. Using halves

He then used two more examples to show visually that his algorithm works: (a) 1/5=1/10 + 1/10 and (b) 1/9= 1/18 + 1/18.

At this point he made his first generalization:

N2: Each unit fraction can be written as the sum of its two halves which are also unit fractions.

Then, he wrote some additional examples in his notebook and again verified them in the *Balance* environment.

Episode Two: Second Algorithm – from unmethodical to systematic experimentation.

Nicodemus decided to work with the same initial unit fractions as in the first algorithm. He mentioned that he had to avoid using the two halves. So, he started with ½ on the left side of the balance and an arbitrary unit fraction on the right side. He had now to put an additional weight in the right side to achieve equilibrium. His choices were guided by the feedback he received from the software. Since his aim was to have in the end a horizontal bar in the upper level he started guessing and checking and then altering the denominators of the second fraction in order to correct the situation and to finally obtain a pair of unit fractions that would have sum equal with the unit fraction on the left side. However, since his experimentation was not following a concrete strategy he wasted his time by wandering around the unit fractions aimlessly. He very soon realized that it was not possible to find the algorithm this way. So, he decided to make a shift in his approach starting a new attempt starting with the fraction 1/5.

N3: I have to avoid using two halves.

N4. So I must start on the right side with a unit fraction smaller than the initial one on the left *side and at the same time different from its half.*

N5: I know how to make smaller or bigger a fraction but this is not enough to guess the correct pair.

N6: So, I can start on the right side with a fraction smaller than the initial and I will gradually start to change the second fraction of the pair in a constant rate to find the correct denominator.

N7: The first smaller fraction than the initial (i.e., 1/5) is 1/6.

Obviously, from the mathematics point of view this claim is not a valid one. We accept that Nicodemus talks in terms of whole numbers so that he can say that the next smaller is 1/6. He was based on the fact that the bigger the denominator the smaller the fraction. His next step was to choose the second fraction of the pair having as its denominator the number 10. He justified his choice by saying that it is easy to double this denominator as many times as he wants checking at the same time the equilibrium of the bar on the top of the screen. Thus he started with 1/10, and then he used 1/20 and then 1/40 receiving each time feedback from the program concerning the equilibrium of the upper bar. The first two showed that he had to continue increasing the denominator to obtain equilibrium. However, the final one showed that he outweighed the correct total. Consequently it was time to make a correction by choosing a fraction between 1/20 and 1/40. The 1/30 gave the solution (Figure 2).

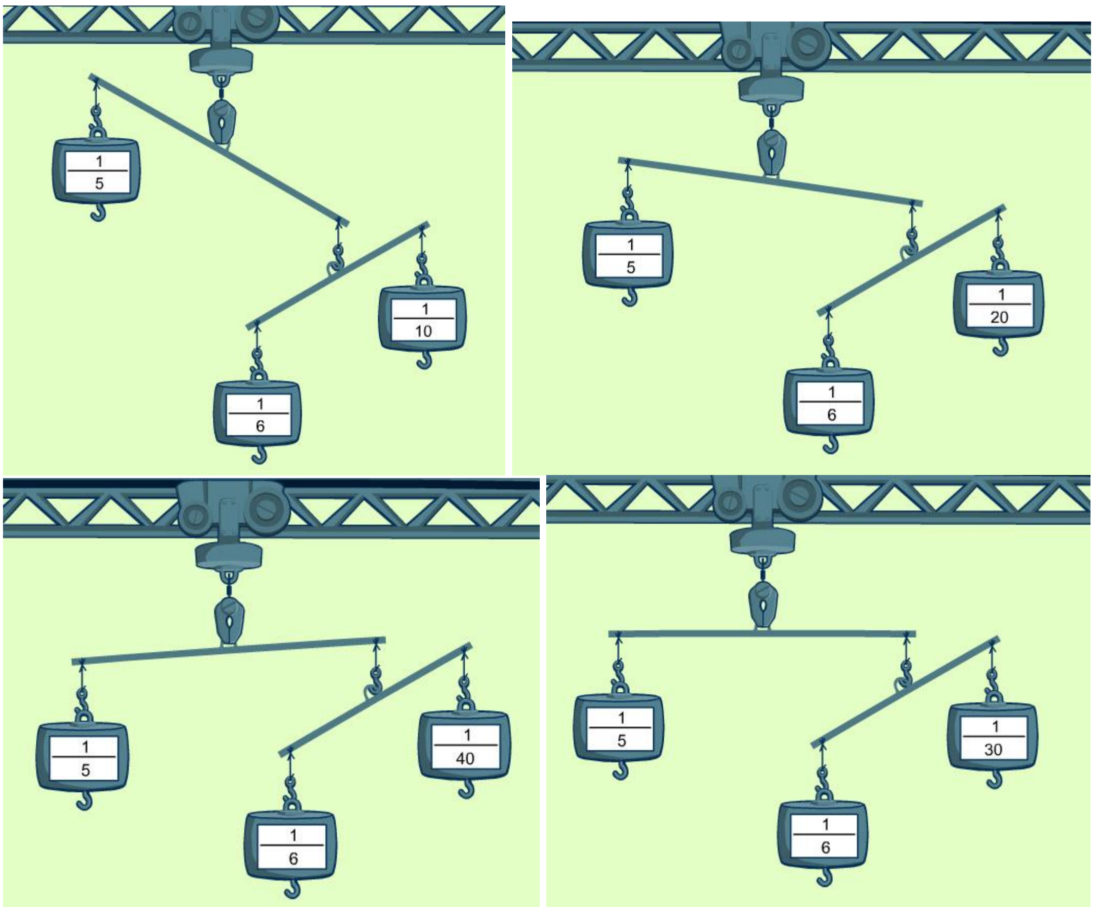

Figure 2. Systematic experimentation

He wrote in his notebook the equation $\frac{1}{5} = \frac{1}{6} + \frac{1}{30}$.

Following the same way of experimenting (i.e., finding the first smaller fraction and then keeping it constant and changing gradually the second one until obtaining equilibrium) he turned to the two remaining unit fractions that were used for the first algorithm. For ½ was more easy to find that $\frac{1}{2} = \frac{1}{3} + \frac{1}{6}$.

For 1/9 he repeated the same pattern as in 1/5. He found the first smaller (i.e., 1/10) and then started to change the denominator of the second fractions following the sequence 20, 40, 60, 80, 100. It was between 80 and 100 when the *Balance* showed that he overweighed the total. He corrected by choosing a unit fraction in the middle between 1/80 and 1/100 (i.e., 1/90) which gave the correct answer: $\frac{1}{9} = \frac{1}{10} + \frac{1}{90}$.

Examining the three examples it was easy for him to find that there was a pattern. This helped him to generalize and state his conjecture:

N8: There is a second way to write a unit fraction as sum of two other unit fractions. You can take the next smaller fraction (increasing its denominator by one) and the second fraction will take as denominator the product of the two previous denominators.

Nicodemus verified his algorithm by two additional examples. For each example, he firstly predicted the pair of the unit fractions and then he proceeded to the *Balance* environment to verify his predictions.

Episode Three: Expanding the second algorithm.

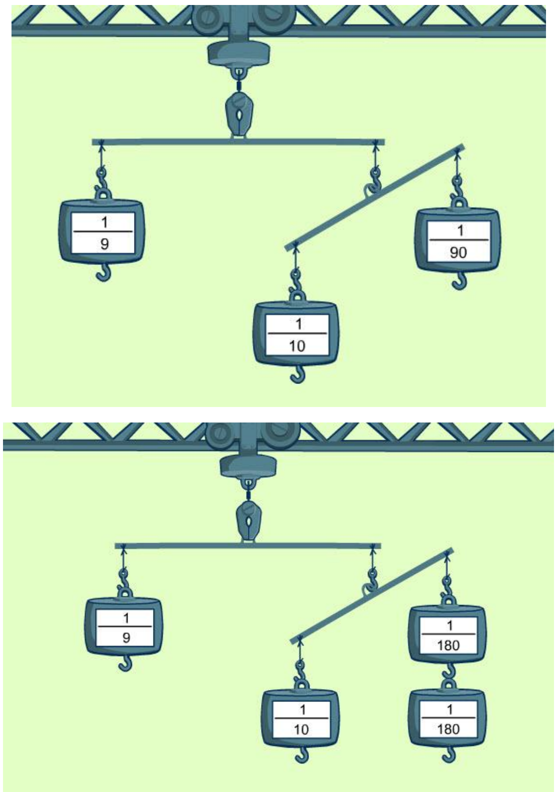

Figure 3. Expanding the second algorithm

After being convinced about his algorithms Nicodemus was asked whether his findings could be used so as to write the fraction 1/9 in his final example as sum of three unit fractions instead of two. His first reaction was to substitute 1/90 with its two halves influenced by his first algorithm. So, his equation became (Figure 3):

$$\frac{1}{9}=\frac{1}{10}+\left(\frac{1}{180}+\frac{1}{180}\right).$$

Immediately, he asked the permission to apply the same algorithm for substituting the 1/10 by its two halves (Figure 4, top). He claimed that this does not influence the equilibrium since according to the first algorithm it is the same to consider 1/10 as 1/20+1/20. He found exciting the idea that he could repeat the algorithm again and he substituted 1/180 by its two halves (Figure 4, bottom):

$$\frac{1}{180}=\frac{1}{360}+\frac{1}{360}.$$

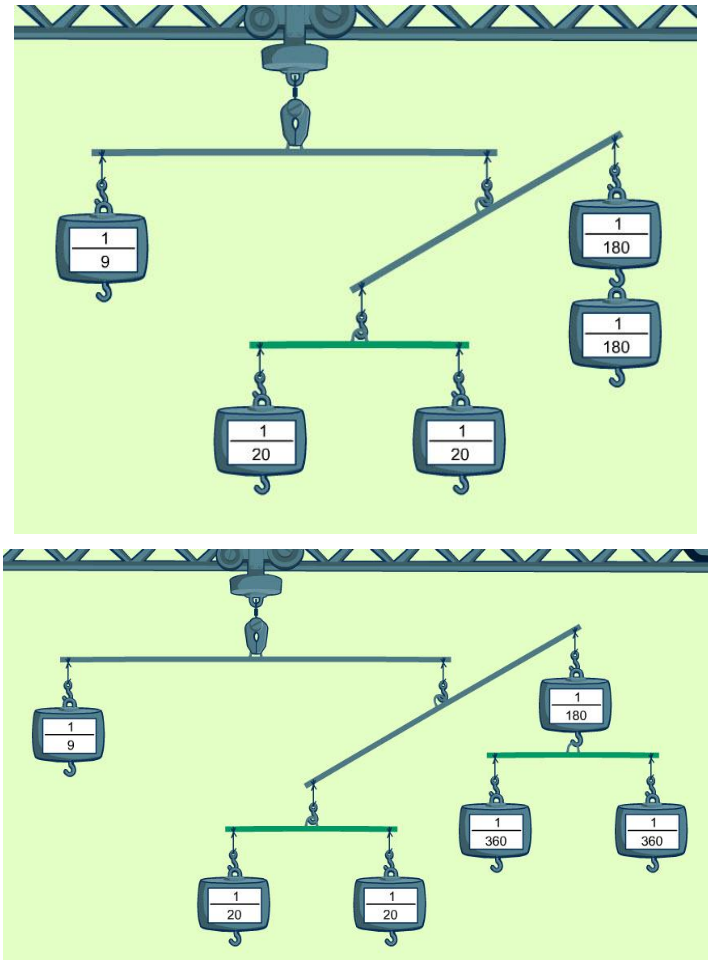

Figure 4. Deeper understanding of the algorithms

It is interesting to point out that Nicodemus was not limited to apply just once more time the first algorithm. He started gradually to suspect that there was something more than the two algorithms.

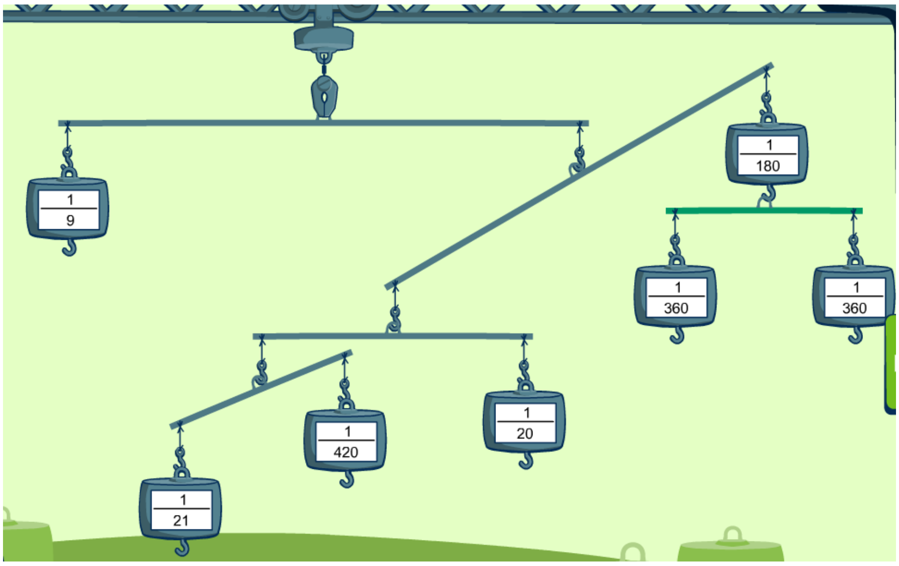

Figure 5. Reaching generalization

He claimed that, since each unit fraction can be written as sum of two other unit fractions this means that it can be applied as many times as he wanted, no matter the side (left or right) of the balance. To show that this is valid for both algorithms he decided to expand his last example by substituting 1/20 with two unit fractions, but now according to the second algorithm (Figure 5):

$$\frac{1}{20} = \frac{1}{21} + \frac{1}{420}$$

The fact is that starting to substitute continually unit fractions with two other unit fractions the denominators gradually were increased and consequently the values of the fractions were decreased. This meant that the change in the slope of the bar on the top of the *Balance* was becoming almost impossible to be noticed. It would be expected that this could cause confusion to the student. However, it is worthy to mention here that during this phase Nicodemus started to ignore the horizontal bar of the balance as a reference to whether the equilibrium had been achieved. He was convinced about the validity of his algorithms and the visual impression was used just to verify his final result rather than the intermediate ones.

At this point he was ready to broaden the initial statement that said that it is possible to find two algorithms that allow each unit fraction to be written as sum of two other unit fractions. After the experimentation that preceded he was able to make a further generalization. The initial statement was correct but could be broaden to become more complete:

N9: Actually, this process can be applied continuously. And any unit fraction can be expanded in a sum of as many unit fractions as we want. The only thing you have to do is to apply one of the two algorithms in order to expand a unit fraction on the right side.

Conclusions

Constructionism as a theory of learning is based on two different notions of construction of knowledge. On the one hand, there is the idea that students learn when they are actively constructing new knowledge rather than waiting for knowledge to be delivered to them. On the other hand, constructionism claims that effective learning takes place when the students are engaged in constructing personally meaningful artefacts which represent their own learning (Beisser, 2006) or when they tinker with an object or entity (Alimissis & Kynigos, 2009). Broadening this perspective the final product of the Nicodemus’ reaction with *The Balance* could be considered an instance of an artefact which indeed mirrors his own knowledge as it emerged through his personal engagement in constructing the asked algorithms.

The way such algorithms are usually taught (at least at the level of primary education) is to present the algorithm accompanied by examples and exercises. This leaves students by the impression that an extraordinary mind some time instantly invented the algorithm. This is why it was our decision to give the targeted algorithms as the task that had to be solved. This demands a systematic experimentation and consequently an environment that would allow the student to experiment is necessary. The realistic behaviour and reaction of the *Balance* software contributed to the construction of the second algorithm. The student's engagement in this interplay with the software made him able to improve his attempts, to formulate and check conjectures reaching thus the construction of the algorithm.

Obviously, for a mathematician, being convinced is not enough to accept the validity of this conjecture. It must be followed by an answer to the question why this is true (i.e., to prove it). However, this is not something that is expected from such young students. What Nicodemus found is important in itself. He modified the initial interface of the *Balance* creating a more complex one that constituted the visual description of the algorithm. This was done by adding new components and/or substituting a component by its equivalent pair of fractions.

Obviously, we cannot make generalizations since only one student was involved and this work is considered a case study. But the findings give support to (a) offer another approach to primary school teachers for letting their students interact with an entity in order to construct their own knowledge, and (b) to set up a future research on the same spirit involving now a sufficient number of participants in order to highlight the potential support of certain computer environments in constructing mathematical knowledge.

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Children Learning about 'Urban Sustainability' through Playing and Re-constructing a Half-Baked Microworld

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Abstract

The study reported in this paper is based on the implementation of an educational activity which was designed to engage Greek students of the 6th grade in collective meaning-making processes on the concept of 'urban sustainability' while collaboratively playing and de-constructing a game microworld. A half-baked digital game on the idea of sustainable city was created by the researchers based on the Sus-X microworld template. The study's findings indicate that the students' understandings of what 'sustainability in a city' pertains seem to evolve as a result of the processes involved in the constructionist activity. Patterns of their interaction with the microworld show that the students managed to realise in varying degrees the existence and interplay of the three axes of sustainability (environment - society - economy). We discuss the learning gains of treating complex and abstract concepts, such as that of sustainability, through applying constructionist pedagogical designs.

Keywords

Sustainability, sustainable city, Constructionism, digital games, half-baked microworlds

Introduction

Constructionist frames of epistemology and learning have been traditionally applied to subject domains such as mathematics education, science education and computers education. Extending constructionist thinking beyond these fields to social sciences, humanities and the arts is a major challenge yet to be undertaken. This is particularly true for educational domains that promote interdisciplinary, systemic and critical knowledge about complex concepts and issues related to contemporary realities such as those dealt within the context of Environmental Education (EE) and Education for Sustainable Development (ESD). Does Constructionism offer new tools along with a new platform for thinking about how to gain new ways of understanding these concepts and issues and consequently how to design learning in these domains in both appropriate and more effective ways? The study reported in this paper has been designed to explore the implementation of a constructionist framework in teaching and learning about the concept of urban sustainability within the context of an EE activity.

Sustainability has become a fashionable word in environmental policy discourse over the last two decades not only among scientists, politicians and policy-makers but also among the general public. It is nevertheless a notion by nature 'difficult' to work with as it lends itself to numerous interpretations (Daskolia, Kynigos & Yiannoutsou, 2012). As a means to overcome the inherent vagueness of the concept, it is suggested to be approached through its core dimensions. There is some consensus that sustainability brings together three different axes: environment, economy and society (UNESCO, 2005). They constitute the tree pillars of sustainability, three interdependent and overlapping systems, the proper functioning of all three is a necessary condition for achieving sustainability. The environmental axis refers to the effective protection of nature and the physical environment as well as the prudent use of natural resources. The economy axis stems from the need for establishing a prosperous and viable economic exchange which has to take into consideration the limits of economic growth and to be based on a redefinition of the personal and social levels of consumption. As far as the society axis is concerned, sustainability has to be founded on healthy communities and to promote democratic and participatory systems and processes that allow free expression of views and the rigorous building of social consensus. Human welfare and rights, peace and the establishment of a sense of security among the citizens, gender equality, cultural diversity and health are some of the aspects which are closely related to the societal axis.

Over the last twenty years the concept of sustainability has been closely associated with education. Learning about sustainability is acknowledged as an essential strategy for achieving sustainable societies and as a tool to enhance quality in educational practice (European Council, 2010). However, current school practices face many difficulties in promoting sustainability due to the resistance placed by traditional school structures, which remain greatly normative and conservative, to respond to this challenge, as well as to the reluctance of teachers to deal with 'difficult' concepts and issues (Stevenson, 1987).

In order to address this problem innovative approaches and pedagogies need to be explored so that children and young people are encouraged to get involved in meaningful educational processes aiming to promote sustainability (Kynigos & Daskolia, 2011; Daskolia, Yiannoutsou, Xenos & Kynigos, 2012). Digital game-based learning is among those fields whose potential for sustainability education rests to be further explored, as it is argued to support the development of important skills, such as strategic thinking, planning, communication, negotiation, group decision-making and data-handling (Kirriemuir & McFarlane, 2004). It is worth noting that the number of digital games on themes related to sustainability has grown exponentially over the last years. The learning potential of some of these software tools lies in that they provide players with opportunities to 'experiment' with applying sustainability principles and virtually experience the consequences to them otherwise impossible to occur in the real world; or that they evoke their involvement as prospective citizens into individual and collective action associated with sustainability goals (Liarakou et al, 2011).

One of the most popular themes addressed by current digital games on sustainability is the urban environment (Liarakou et al, 2011). Contemporary cities as complex agglomerations of human-made and physical environmental systems are among those cases offering many opportunities for identifying, defining and testing the application of sustainability. According to Yanella and Levine (1992) all initiatives towards sustainability should be centred on strategies for designing, redesigning and building sustainable cities. Although many would see the city as an ecological entity or as the extended version of an ecosystem (Newman, 1999), the idea of the sustainable city calls for a more elaborated and systemic conception of all its interconnected components (social, cultural, economic, and environmental) and for a consideration of the impact of our choices and everyday practices on each of them. For a city to be regarded as sustainable it has to be designed, run and lived by people who not only take into account how to protect its natural environment and how to minimize their inputs (in terms of energy and other resources) and outputs (in terms of the waste produced and the pollution caused) (Register, 1987). In a sustainable city people have to regain control of their communities, cultural diversity needs to be protected, urban violence to be reduced, while the economy has to be self-sufficient and contributing to local wealth, energy conservation and reutilization of resources.

In this study we designed and implemented an educational activity with the aim to engage students in addressing the complex and multi-faceted character of 'urban sustainability'. Playing and re-constructioning a game microworld were employed as pedagogical strategies to incite students to identify and delve on the game's embedded concept of sustainability and to help them frame their own view of a 'sustainable city'. Our approach moves within a constructionist perspective viewing learning as an experiential process of collaboratively constructing knowledge through active engagement with the construction and de-construction of meaningful digital artefacts with the use of microworlds, that is appropriately designed technological environments and tools (Papert, 1993; Kynigos, 1995). By following this approach we made use of the technological and pedagogical construct of 'half-baked microworlds' (Kynigos, 2007), that is pieces of software explicitly designed so that their users/ learners would want to build on them, change them or de-compose parts of them in order to construct artefacts that better suit their ideas of the concept, phenomenon or situation represented by the microworld. In this sense, the microworld grows along with the knowledge of its users (Hoyles, 1993).

The study

A half-baked game microworld (Perfectcity) was created by the researchers based on the idea of the sustainable city. Our aim was to employ it as a pedagogical tool within the context of an educational activity focusing developing understanding among 6th grade students on the concept of sustainability. The main research question was to explore whether and in what ways the students' collaborative play, de-construction and construction of the Perfectcity microworld could support learning about sustainability.

The Perfectcity Microworld

We constructed the Perfectcity game microworld (see Figure 1) based on the Sus-X template (http://etl.ppp.uoa.gr/_content/download/eslate_kits.htm), a digital authoring system for SimCity-like games. This is a game template which leaves open to user manipulation, construction and de-construction the part of the mechanism that contains the 'model of sustainability' upon which the game is built, while keeping away the syntax and the information that might be noise for the users. Perfectcity consists of the map and the main sites of an imaginary city. In order to play the game users have to decide which sites to visit in a city in a sequence of 10 possible moves. While playing users have to take into account (a) the indicators and values of each site, (b) the changes in their "resources" caused by visiting sites and (c) the possible risk to run out of "resources" before the time set for ending the game.

The idea of the city represented by the game is one allowing for a few sustainable and many more unsustainable choices. The eighteen city-sites that were chosen by the researchers to appear in the city map are: the power station, the recycling plant, a landfill, a car parking area, a park, the car and the metro (as two means of urban transportation), as those city-sites referring more to the axis of environment; home, cinema, a library, the City Council and a volunteer work agency, as those sites referring to the axis of society; and the office, two shopping centers (the Mall and Golden Hall), two fast foods (Goodies and Mc Donald's) and a supermarket, as those sites more related to the axis of economy. The criteria against which each of the sites was evaluated were chosen by the researchers to represent the three axes of sustainability (environment, society and economy). The environmental dimension was expressed by the criteria of ‘energy’ and ‘waste’; society was assessed by the criteria of ‘contentment’ and ‘citizenship’; nevertheless, no criteria for evaluating the economic dimension of the city-sites were used. The specific criteria were chosen by the researchers because they were considered important for a good function of the city and at the same time easy to be understood and employed by 6th graders.

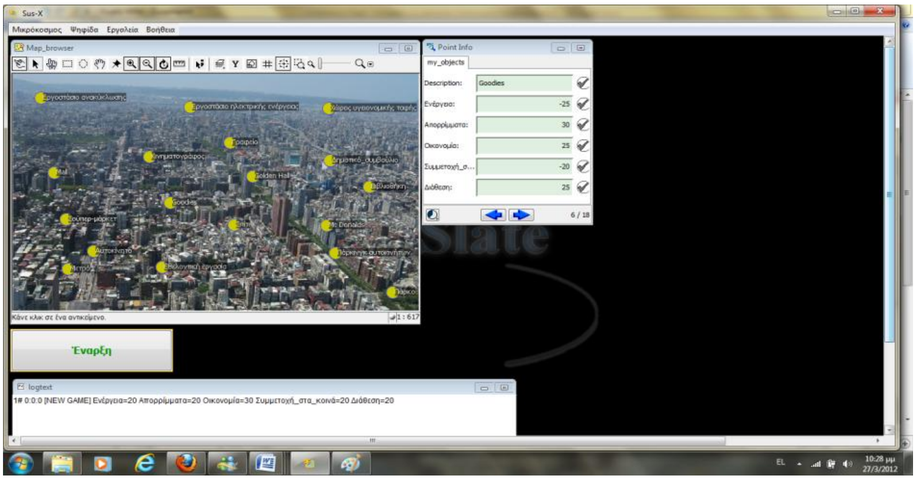

Figure 1. The Perfectcity microworld

Perfectcity is based on the principle of purposefully inciting students to identify and question the sustainability idea on which the game’s model of the city was built as they interact with it. In doing so the students are expected to discuss and reflect on it in terms of both the infrastructures provided by this city and the practices its citizens are involved in. In the study reported in this paper the students were first asked by the teacher to play the game, then they got into a discussion about the sustainability of the city with the moderation of the teacher, and finally they collaboratively deconstructed and re-constructed the game microworld to better express their own conception of a sustainable city.

Participants to the study and stages of the educational activity

Six students – three boys and three girls- participated in the study. They were all 6th graders from a Primary school located in the wider Athens area. Participants were asked to take part in a study and contribute to the design of a new educational digital game. The activity took place in a school classroom and the necessary equipment for running the study (such as laptops) was brought from the school’s computer lab. The students worked in pairs during two face-to-face meetings for about five hours in total.

In their first two-hour meeting the students played Perfectcity. They were given 10΄ to decide and select ten sites to visit by taking care that their choices would not make them run out of resources. They could complete at least four successful paths. While playing the students were asked by the teacher/ researcher to think about how ‘perfect’ this city was and what kind of problems it may face. After the play the teacher (3nd author) initiated a discussion among all students about the model of the city represented by the game, how far from the ideal this city was, what were the problems identified by the students and what changes they could make to improve it.

During their second (three-hour) meeting the students were told they were able to modify the idea of the city represented by the game to get closer to sustainability. The teacher/ researcher introduced the students to the functionalities of the Sus-X microworld template and explained the variety of options they had. No special technical skills were required for the students to use the Sus-X template to design and construct a new game. Although they were allowed to make as many modifications in the game as they wanted to, the students focused mainly on those having to do with whether to keep or change the city background, whether to keep or replace the sites on the city map, or whether to alter the criteria already used by the game and the values attributed to the sites.

The whole activity was moderated by the teacher who provided all necessary information to assist the students in their task, she posed questions to initiate meaningful discussion among them and supported the groups in identifying their own ideas of the sustainable city.

Data collection and analysis

Audio recording and screen capturing software was used to collect information on the students' discussions and actions while interacting with the microworlds. In addition the teacher kept notes on the process. The audio recorded data were transcribed and thematic analysis was applied to them (Boyatzis, 1998). The screen capturing data were analyzed to identify the students' moves and choices while interacting with the microworld.

Findings of the study

Students play with Perfectcity

The students' response to the teacher' suggestion of playing Perfectcity was quite enthusiastic. However, each group engaged with it in a different way. Although all three groups succeeded to complete four paths as they were asked to do and they all developed an awareness of the internal logic of the game, each of them followed a different approach. As a consequence, both their degree of familiarization with the game and their choices with regard to it varied.

The first pair of students (two boys) got familiar with the game and how they should play to win quite easily. They tried seven different paths, four of which were successful. After some first failed attempts they came out with a strategy to play the game. Following that, their choices were not random but based on a careful consideration of the points they would gain if selecting a site and on an estimation of their overall performance (the aggregate score) on the game. The selected city-sites selected showed a greater concern for the environment compared to the other two axes. The criteria that were mostly employed by this group were predominantly environmental (energy and waste). The next episode is quite characteristic of showing this group's concerns while playing Perfectcity:

S2: We got 90 [in terms of energy]. Isn't it a good score? And now our score in 'waste' becomes 50…

S1: What do you think if we go back and visit the 'landfill'?

S2: Right, yea, that's cool my friend!

Satisfaction from visiting the various sites was also an important criterion that led this group's choices. Least attention was given to 'citizenship' concerns and, not surprisingly, the choices in terms of the sites selected did not include any economic aspects of the city life. Their strategy was mainly focused on reducing waste and increasing energy.

The second pair of students (2 girls) met various difficulties while playing the game. Compared to the other two groups it took them more time to grasp and understand the internal logic of the game. As a consequence they followed twenty two (!) different paths while only four of them were successful. Their game play performance was characterized by deliberately ignoring almost all warning messages and by randomness in most of their choices. Their final and more successful attempts were mainly characterized by environmental concern. In terms of the criteria used this group cared more about the energy consumption and waste production impact of their choices.

S2: We have to choose to visit a site to get more energy.

S1: What about the 'power plant'?

S2: If we select the 'subway'? [she clicks on the 'subway']... What is its 'energy' value? -30. Mmm! We'll lose much of our energy if we go there…

S1: Look at this, that's the one we need [she clicks on 'power plant']… It will give us 50 points on energy!

S2: Yes, let's pick it up. ['power plant' is selected]

The third group (one boy and one girl) faced some difficulties in getting into the game's rationale. After several unsuccessful attempts they managed to complete four paths. It took them many random choices to realize how it works and in order to identify a "winning" path to follow. As opposed to the other two groups, this group did not spend much time in looking at the criteria and the values of the various sites in order to decide what to choose. However, despite the initial randomness in their choices they gradually came to realize that there is some kind of interdependence between visiting a site and getting or losing points in the various criteria. They ended up considering the economic dimension of living in a city and they even examined which sites would augment the economy of the city. During their second successful path they managed to realize that many economic activities have an environmental impact:

S2: Economy, we should add some economy…

S1: Economy. Yes, ok! But, how do we add economy in this city? If we visit 'the Mall'? [They click on 'the Mall']...There is a lot of economic transaction going on there… I've told you so.

S2: Yes, but there is also a lot of waste produced there…

In another iteration of their game play this group concentrated mostly on the 'energy' dimension and tried to get the highest score on this criterion. They applied the same strategy (focus separately on each particular criterion). What is quite interesting is that at the end they put together all the various criteria and combined them in their last iteration of playing Perfectcity. By doing so they actually managed to view urban sustainability in a more holistic way, by taking into account all three axes of sustainability.

S1: [They click on the 'recycling plant'] Yes, it gives us 20 points on 'citizenship'. We should select it. You see? It decreases 'waste' as well!

S2: Yes, you're right! It reduces waste!

S1: We'll have -5 on 'waste'.

S2: What about the economy? What we gain in terms of this? [They refer again to the recycling plant]

S1: What does it mean having -5 on waste? [they ask the teacher/researcher]

Students construct their own Sustainablecity games

During the second phase of the activity the teacher explained that the students could intervene in Perfectcity, de-construct it and construct a new game. This was a real challenge to the students to which all groups responded with much enthusiasm. A discussion among all was preceded with the moderation of the teacher during which the students were aided to realize how "imperfect" the city model represented by Perfectcity was and to identify possible changes to improve it and make it more sustainable.

All three groups decided to change the picture/map of the city in Perfectcity. The teacher provided them with 15 alternative pictures of cities and asked to select the one it was closer to the city their view. Subsequently, all groups either deleted or added new sites on their new city map. None of the three groups did they alter any of the criteria already incorporated in the game or introduced new criteria. However, the students had the chance to re-think of some of the criteria, such as those of 'energy' and 'economy', and admit that there was some confusion, misunderstanding or doubt about the actual meaning of them. For example, almost all the students equated the 'energy' of the city with the individuals' personal energy while some of the students confused economy as a structural societal process with home economics or money-saving practices. There were no major changes by the groups in terms of the initial values, check conditions and end conditions of the game, probably because of the time limitations of the activity.

As far as the changes implemented by each group, the first group retained twelve sites and added ten new ones. As a first step they decided to leave out two sites related to car transportation in the city (car and car parking area). Instead, they suggested the use of metro and bicycles as the most appropriate means of transportation in a sustainable city.

S2: That's why we don't need cars. Because all the people commute on their bicycles.

The students kept those sites related to energy production – the energy plant and the landfill – and added one more, photovoltaic, as a greener (renewable) energy source. They also deleted one site related to society – the town council. However, they added seven new ones: the primary school, the high school, the college, the gym, the ice skating rink, the playground and the health center. It is worth noting that among these sites there are three purely educational contexts (primary school, high school and university) and three sites combining recreation with sports (ice skating ring, playground and gym). It is obvious that their selections were based on some kind of projection of the students' everyday zone of experience in the city. This is why places of economic activity, such as the office and the second shopping mall, were left out. Since the students were least concerned about these places there was no point of keeping them on the map. An additional reason why the students left out the second of the two malls was its perceived negative environmental impact.

G1-S1: The city has two shopping centers, which both produce a lot of waste and consume much energy. We could have just one, downtown, and whoever wants to shop could go there.

It is worth noting that although the students' choices during game playing were mainly concentrated on the environmental aspect of the city, their engagement with the microworld while constructing their game made them consider the other two dimensions of sustainability too (society and economy). The game created by the first group consisted of six sites referring to the environment aspect, twelve sites referring to the society aspect and four sites referring to the economy aspect. The new values added in each of the criteria were not realistic or a result of thought. Some of them were chosen only for the sake of the game's usability without the students being able to specify the true values (e.g. the value given to University on 'satisfaction' was -35).

The second group kept seven sites of Perfectcity and added ten new ones. Similarly to the first group they retained those sites related to energy production while they added photovoltaic. They showed particular concern on transportation as they identified it a major culprit of urban air pollution. As a result they deleted all means of transportation of Perfectcity and added a cycling road.

R: We live in Athens, which is a big city. What problems do we face in this city?[from a discussion between the teacher and the students]

S2: There are a great number of car vehicles; their exhaust gases pollute the atmosphere.

The groups deleted four sites having to do mostly with the social axis: cinema, town council, library and home. Similarly to the first group they added seven new ones: the swimming pool, the playground, the ice skating ring, the private high school, the health center, gym and the water sports center. Again, their thinking parameters for selecting these sites were that they were related to education and entertainment, both close to the students' way of life.

In terms of the city sites that mainly related to economic transactions, it was this group's choice to leave out the two fast food restaurants, one of the two shopping centers and the supermarket. Instead, they added 'hotel' on the grounds that tourism is among the main sectors of a city's economic development. Their game consisted of seventeen sites, six of which were closer to the environment axis, eight to the axis of society and three to that of economy. Again, this group moved from focusing only on the environment when playing Perfectcity to recognizing society as among the city's sustainability dimensions. The values the students gave to the criteria for evaluating the city-sites were decided based simply on how much they added to the game's usability.

S2: We have given much higher values to some sites…

S1: We'd better use some negative values too.

S2: Yes, because otherwise the game won't work.

The third team made fewer changes than the other two. They kept twelve of the initial city-sites and added four new ones. Similarly to the other two groups they kept all sites that were adding to the city's energy. They were also concerned about transportation: they deleted 'car' and 'car parking' and added a new one, the 'cycling road'.

S1: Did you leave the 'car'? Delete the 'car'. This city doesn't have cars. [They also delete 'car parking']. We don't need cars.

From the society axis they deleted three sites: home, cinema and the volunteer work agency. They replaced them with gym, a football pitch and the school. They also left out the second fast-food restaurant (Mc Donald's). The game they constructed consisted of sixteen sites, six of which were much related to the environment, five to the society and five to the economy axis. They managed to apply a more balanced representation of the three sustainability components in the city. As far as the values with which they valued the criteria, they came out from much discussion and negotiation among the students.

S1: What value should we give to this site on 'energy'? Should it be positive or negative?

S2: Negative.

S1: Ok, negative.

S2: -20? -25?

S1: I suggest -25.

Concluding remarks

This small-scale study applied a constructionist framework to support primary education students' learning about 'urban sustainability' through playing and re-constructing a digital game microworld. The findings of our study indicate that interaction with the game microworld as an "object to think with" (Papert, 1993) aided the students to be introduced to the abstract and difficult concept of sustainability through engagements with more situated, appropriate and enjoyable learning activities, and to gradually develop a more balanced understanding of it, by identifying the interconnection among its various components (environment-society-economy). They almost unanimously started with equating sustainability with its environmental dimension whereas at the end of the activity they were almost aware of the interconnections among all three axes. This can be viewed as a learning gain since research confirms a strong tendency from either learners or the general public to ascribe sustainability solely to the sphere of environmental management (Liarakou, Daskolia & Flogaitis, 2007).

Our study provides some evidence that the constructionist perspective applied to the pedagogical design of the activity supported students in identifying and formulating their ideas on 'urban sustainability' and in implementing them along with the design of the game. The microworld environment (the Sus-X template) offered not only the actual context where the students could construct their artefacts but also a structured agenda for them to think and share their ideas about the concept at stake. Thinking and learning about such an abstract and complex concept became more situated and thus more appropriate to the students' developmental readiness to deal with it. The students were more motivated to learn by being engaged in a playful task, far away from the instructionist logic of their curriculum. However, there seems to be an additional pedagogical potential in treating the microworld as a digital artefact both with a hidden conceptual and ideological logic that remains to be revealed and with an overt structure of specific functionalities that rests to be employed for re-construction and for the construction of new artefacts. In our study, the students were scaffolded to express and discuss their ideas on sustainability 'in the context of' playing Perfectcity and while employing the Sus-X template to construct their games. They wouldn't do so otherwise or anyhow, as it is not a natural process for them to focus and delve on the coordinates of such an abstract theoretical construct. However, they were aided into unravelling these dimensions and 'tinkering' with them both while playing the game and when considering what concrete changes to implement in the microworld in terms of the map to upload or the sites, criteria or values to change or add. The social context that was created from the teacher's intervention throughout the implementation of the activity and the exchange of views among students within the three groups facilitated the initiation and sharing of ideas.

This study gives some insight into the development of children's understanding of the complex concept of sustainability as a result of engaging with game-playing and game-design processes. However, more future research is needed to explore how the development of knowledge about environmental and sustainability concepts and issues is enabled during such processes, whether and how these knowledge gains are transferred to everyday life or other contexts, as well as to investigate all possible benefits EE and ESD can have via applying constructionist learning frameworks.

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Bifocal Modeling in Biology: Linking and Comparing Virtual and Real Experiments

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Abstract

In this paper we describe a pilot study of an approach to STEM inquiry learning called Bifocal Modeling (Blikstein, 2010) with a group of high school students studying bacterial growth. Students grew and measured real bacteria, and then collaboratively designed a conceptual agent-based model of bacteria. Observations and student notes suggest that the activity helped students demonstrate their knowledge of bacterial growth by formalizing it from a list of unorganized facts into an accurate pseudo-computational model. In the process of completing their task, they also critically reflected on the assumptions built into the modelling activity itself, and demonstrated familiarity with some core principles of complex systems.

Keywords (style: Keywords)

Virtual Experiment, virtual model, physical model, Bifocal Modeling, computer modeling, agent-based modeling.

Introduction

The use of computational models of scientific phenomena has become an increasingly viable option for classroom science learning as technology and accessibility improve. There is a large body of literature on the use of those virtual models to display data, to simulate complex phenomena, and to permit student experimentation in domains that might be costly, impractical, or dangerous (Jaakkola & Nurmi, 2008; Finkelstein et al., 2005; Klahr, Triona & Williams, 2007; Zacharia 2008a, b; Resnick & Wilensky, 1998; PhET, 2011). The potential of a combination of virtual and physical models for science learning has been documented for a wide range of ages and domains. For instance, Liu and collaborators (2006) explored high school students' understanding of chemistry concepts. They found that the combination of a virtual model and hands-on lab activity was more effective than either alone, balanced for time-on-task, in promoting students' conceptual understanding of the gas laws. Recent studies have also investigated the importance of the sequencing of physical and virtual model activities on student learning, with the general result that better learning resulted from the virtual experiment following a physical one (Gire et al 2010, Smith et al. 2010).

However, the literature has focused almost entirely on pre-designed physical and computer models. Pre-designed models can scaffold and direct students to attend to relevant problem information, but they fail to give students opportunities to evaluate the assumptions and limitations of the models themselves (Papert, 1980). Creating and critically evaluating models is an important part of scientific practice, and is being increasingly recognized as a valued educational goal (Levy & Wilensky, 2008; Blikstein & Wilensky, 2010). The literature has also under-explored the potential for deeper support of student comparison between the physical and virtual models. Smith and collaborators (2010) noted that scaffolds in the virtual model, or direct data-sharing between virtual and physical, could help students to see the similarities and differences between model and reality.

In this paper, we present a pilot study that demonstrates a pedagogical framework to augment the comparison between real and ideal systems as an avenue to deeper understanding of biological phenomena. Using a type of scientific inquiry activity called Bifocal Modeling, high school students built virtual and physical models of bacterial growth in order to learn content knowledge, computational thinking, and critical meta-modeling skills. Our main research questions were: (1) how do students' understand the mismatch between idealized and physical models?, and (2) how do they critically evaluate their choice of variables and phenomenal factors to include (or not) in their own theoretical models to iteratively match it to the real-world data?

Research setting

Bifocal Modeling (BM) (Blikstein & Wilensky, 2006, 2007; Blikstein, 2010, 2011; Blikstein, Furhrmann, Greene, & Salehi, 2012) is an approach to inquiry-driven science laboratory learning that challenges students to build and relate in real time physical and virtual models. In these "hybrid-reality" activities, students explore a scientific phenomenon such as heat diffusion, the properties of gases, or wave propagation by designing and building their own physical model and collecting data using embedded sensors. In parallel, they build their own virtual model of the same phenomenon, and can compare the behavior of the virtual model and the physical model in real-time (figure 1). The most common software to implement virtual models has been NetLogo (Wilensky, 1999), a free and open-source environment for agent-based modeling. A NetLogo model typically consists of a set of autonomous agents (such as gas particles or people at a party) moving through a world and interacting to produce emergent outcomes. Students define the variables held by the agents and the world, and specify a set of rules for agent-level behavior, such as "if two gas particles collide, they exchange energy, and bounce off each other." Their goal is to build a model whose behaviour matches the data they collected. This challenge encourages students to refine their content knowledge as they iteratively improve their virtual models, and to question the validity of their own representational choices. For example, a student trying to match a computer model of Newtonian motion to a real experiment may be forced to confront the existence of a missing friction coefficient, to determine how to measure motion using a given set of sensors, or even whether to model an object as a single unit or as a collection of atomic particles. In this way, BM can serve as a method to learn scientific content, modeling skills, and scientific research methods.

The growth of bacteria has been an exciting object of study for centuries. We chose bacteria as a subject because of their simple cellular structure and quick reproduction rate, allowing them to be used to address many biological questions as model systems. Bacteria can also be used to demonstrate exponential growth, which can be used to model more complex ecological dynamics.

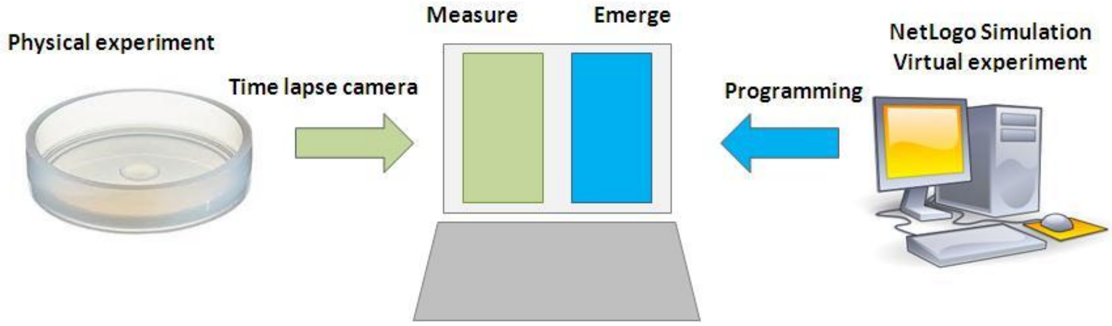

Figure 1. Bifocal Modeling platform, linking a physical experiment and a computer simulation in real time.

Methods

The authors conducted a pilot study in the form of an after-school workshop for four high school students, all female and ranging from 9th to 11th grade. Two had previously learned about bacteria in class, but knew nothing about the growth pattern of bacteria, and had never grown real bacteria. The workshop was conducted in a laboratory setting and lasted for a total of about five hours, split across three afternoon sessions. Even though Bifocal Modeling activities typically take 20+ hours, for this study we attempted a design experiment to fit the activity within a format that would be more realistic for a school implementation within a typical biology unit. Therefore, we attempted to shorten the activity while trying to keeping its core design principles. The first change was to shorten the data collection phase by offering students the opportunity to create their own experiments (growing bacteria), but also providing some previously collected data (movies of bacteria growing). The second decision, which emerged during the activity (Design-Based research, Confrey, 2005; Edelson, 2002), was to teach only the conceptual principles of the computational modeling language, since learning a programming language in a 3-hour period would be challenging for most students. Therefore, we adopted a version of "paper modeling" (Blikstein, 2009) and students collectively built agent-based rules of the computer model on a whiteboard, going through their pseudo-code and animating it "frame by frame."

During the first session, the students were tasked with growing real bacteria using supplied tools. They collected bacteria samples from different places around their environment (e.g. doorknob, touch screen, hand, and keyboard), and each student prepared a Petri dish with agar and applied the bacteria to the dish. When finished, they installed a provided time-lapse camera that captured images of the dishes every 30 minutes for five days. The images were automatically compiled into a video that showed the students the growth pattern of the bacteria. For this particular design, we condensed the physical data-collection portion by also providing students with previously-captured movies of bacteria growth and a growth curve, so that they could start the modeling task earlier. We explained that the growth curve was what they could expect to see in their own bacteria cultures, and challenged them to learn about the growth curve in order to make a model of bacteria that could reproduce it and fit the curve.

During the second session, the students were grouped into two pairs and each pair used a computer to do web research on the bacterial growth curve. As they searched, they took notes on information they thought was relevant. The authors were present to remind the students that their goal was to understand what causes the characteristic growth curve. An acceptable answer would be that a typical growth curve contains several distinct phases as the bacteria adapt to their new environment, consume food and release waste, rapidly multiply, and eventually die out from their own waste products and lack of food.

For the third and final session, the authors intended to have the students use the NetLogo simulation environment to make a virtual model. But due to the challenge of learning NetLogo programming in a short period of time (see above), the authors instead conducted a variation of "paper modeling" (Blikstein, 2009) in which students collectively designed and ran an agent-based model of bacterial growth on a whiteboard. This required articulating the variables in the model (such as bacteria count, food, waste, and moisture), and agent-level rules such as "each bacterium subtracts 2 units of food from its location and emits 1 waste."

The students would "run the model" by enacting its rules on the board to progress the model by a single time step at a time, and then stop to add or change rules and variables. The authors scaffolded the modeling session with minimal questions, such as "What is still missing from our model?" and "How can you express the idea of eating food in terms of the variables we have?" The resulting model was "executed" on the whiteboard for enough time steps to give students a sense of the growth curve, and simulated a colony of bacteria that moves, consumes food and moisture, excretes waste, reproduces, and can die from starvation or poisoning from toxic waste. We are well aware of the differences between computational and non-computational media (diSessa, 2000; Papert, 1980), but for the research goals of this study, this adaptation was successful at enacting the initial stages of the computational modeling process, which was enough for our specific research questions. In fact, after the whiteboard activity, students did interact with actual computer models, but that data is not reported here since our focus in on the early exploration of agent rules and real-world data.

Students were given two open-ended questionnaires about bacteria and the growth curve -- before and after the entire session. They were also videotaped during all activities, their computer usage was documented with the Camtasia screen-capture software, the researchers took field notes, and their notes and sketches in all three sessions were preserved.

Data and Discussion

This section will consist in a commented narrative of several classroom episodes centered around the perceived and hypothesized affordances of BM, namely: (a) resolving model mismatch, (b) converging on appropriate variables, (c) critically evaluating the assumptions of models, and (d) translating between micro and macro perspectives.

Iteratively improving the virtual model to resolve mismatch

Overall, the group's method was to "run" their whiteboard virtual model in order to see how the bacteria grew, to compare the results to their goal of the growth curve from the physical data, and to resolve the perceived differences between the two by adding rules and variables to the virtual model. They repeated this process a total of four times in the 1.5 hours of the session, developing an increasingly accurate model in the process (figure 2).

For example, a student observed at one point after "running" the virtual model that their growth curve was increasing exponentially from the start. She noted that this was not correct, because the real growth curve had an initial flat "lag phase" before beginning to grow. After a moment's reflection, she remembered that this was because real bacteria have an initial phase of settling into a new environment before multiplying. She said "We need to make a rule that it takes time before the bacteria grow." Another student chimed in, saying that this would have to be different from a maturation period for individual bacteria, because it would apply only to the first bacteria on the dish. After more discussion about how to code the lag phase in their system, they came up with the following rule: "If a bacterium is in the first generation, it has to wait two time steps before reproducing." Upon running the model again, students could see from the resulting curve that they had successfully created the lag phase. The students went through a similar process to add all of the variables in their model.

- add bacteria, food, moisture, temperature

- add rule: bacteria move around randomly

- RUN MODEL: results were a flat growth curve

- add food rule: bacteria absorb food and moisture

- add waste rule: bacteria release waste

- add reproduction

- RUN MODEL: results are exponential growth and no death

- add death rule: if bacteria don't get food/moisture, they die

- RUN MODEL: results were exponential growth and then death

- add lag phase rule: first generation takes longer to multiply

Figure 2: A chronological list of the additions the students made to the model, and the instances in which they ran it. The results of each run prompted a subsequent rule addition that made the model more accurate.

Converging on appropriate variables

When the students were searching the web for information about bacteria, they collected and wrote down a great deal of information that was not necessary for the modeling task they were given. For example, some students noted that bacteria are prokaryotes, eat many types of human food, and live in a range of conditions. However, during the whiteboard virtual modeling session, the students only included variables that were necessary to define the shape of the growth curve - food/moisture, waste, and bacteria health. Global variables like temperature and oxygen affect bacterial growth, but the dynamics of the curve assume that these global variables are constant or the variations are too small. The fact that the students left these variables out without prompting suggests that they implicitly understood this instance of a controlled variable.

Students also made decisions regarding the granularity with which to describe variables. One student noted multiple types of bacteria nutrients in her web research, but went along with the group in representing food as a single variable of just one type. When asked about this issue, she replied that "I don't need to be that specific for this model."

Critically evaluating the assumptions of models

In addition to learning about the relevant variables for modeling bacterial growth, the students in the Bifocal Modeling workshop spontaneously reflected on the underlying assumptions of their models themselves - in this case, their representations of space and time. Space is represented in NetLogo as a grid of square "patches", units of space that can possess variables like location or food concentration. This patchwork representation of space was explained to the students at the start of the whiteboard modeling session, but at the time of introduction it was only relevant as a way to explain how to represent environmental variables like food. However, as the session progressed the students noticed that their bacteria were scattered randomly across the surface in their model, and filled the entire surface uniformly as they multiplied. In contrast, the real bacteria that they grew formed small circular spots. How could they explain the difference? A discussion on how far bacteria can move quickly led to the question of the size of whole grid square itself. As one student put it, "This square could be a whole dish, or it could be just a tiny spot in the real Petri dish… if we were looking through a microscope, zooming in, they [the bacteria] will move much more. " At the end of their discussion, they decided that it was up to them to define the size of the virtual world they designed.

Similarly, time in NetLogo and the whiteboard model is represented as a series of discrete steps called "ticks." While discussing the proper time delay for the lag phase, one student realized that they had no agreed conversion between ticks and real time. She asked, "Do bacteria get food and moisture each minute? Each hour? Each day? Right now we are just doing this with ticks... how can we translate the tick into real time?" At the end of another discussion about the time scale of bacteria growth in the real world and in NetLogo program, the students decided that if bacteria can multiply every 20 minutes, they will agree that one tick in the virtual world equaled 20 minutes in the physical world. Though they did not entirely resolve their questions about representing time and space in their model, the students were asking the "right" questions; that is, they were asking questions about the assumptions that models make about the world, which are at the heart of scientific critical thinking (Blikstein & Wilensky, 2007).

Finally, the whiteboard modeling activity demonstrated the usefulness of computer models to the students. Once the whiteboard model was slightly complex, it became virtually impossible for a person to track the variable values of all of the bacteria and patches. As one student noted, "…it's going to be really hard to imagine this in our heads. This is definitely where a computer model is relevant."

Translating between micro and macro perspectives

A final theme that arose during the modeling session was the continual switching of perspectives, from the rules for an individual bacterium to the emergent behavior of its entire colony. The literature on complex systems education suggests that people find it difficult to move in either direction between macro and micro perspectives -- either inferring the emergent result of a micro-level change to a system, or predicting the micro level changes that could cause a given macro-level result (Wilensky & Reisman, 2006; Wilkerson-Jerde & Wilensky, 2010). Complex system dynamics are also typically taught only in highly advanced math and science settings. However, the literature also suggests that properly designed activities can help people to grasp complex systems concepts much more easily. The iterative process of modeling that students went through can be seen as a process of writing rules at the level of the individual bacterium in order to create emergent outcomes at the level of the colony. With no prior academic knowledge of agent-based modeling or complex systems, the students in this study managed to describe and manipulate a complex system at both levels, micro and macroscopic. While BM is not inherently bound to a complex-systems framework, the data suggests that the process of modeling a phenomenon was an effective way to intellectually engage students with the dynamics of complex systems.

Conclusions and next steps

Instructed to make a model that recreates the bacterial growth curve, students used their previously-learned knowledge about the curve and the physical appearance of the bacteria as a benchmark for what their model should produce. The clash between the virtual and real models defined a clear goal for the students in recreating the bacterial growth curve. In the process of this reconstruction, we claim that the students demonstrated learning in three areas - content knowledge about bacterial growth, critical evaluative skills for scientific models, and an understanding of the concepts of emergence and exponential growth in complex systems. Future work will continue to develop BM as a platform for real-time linking of physical and virtual models, and for real-time collaborative programming with computational media.

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Meanings for 3d mathematics shaped by on-line group discussion

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Abstract

Several attempts have been made to design and study social aspects of constructionist learning that built on the idea of distributed cognition or collaborative knowledge-building within an on-line community of learners. Here we describe designs and activities of a European project titled Metafora (from meta-forum), where the focus moves to learners' reflections on their group work, a kind of meta-cognitive group think. The paradigm was to encourage students working communally to learn how to learn with and from each other as they work to collaboratively address challenging problems in science and mathematics. For this purpose, a web-based digital system that supports this "learning to learn together" (L2L2) approach is being developed. We study students' meaning making processes in this context and the ways they interacted with a beta version of the system, as they worked with an incorporated half-baked microworld in 3D Turtleworlds consisting of a buggy 'Twisted Rectangle'. We try to show how students' meanings were shaped and influenced by learning to learn together aspects that came forward as they shared and discussed their ideas and plans through the system L2L2 support tools.

Keywords

3d geometry, collaborative meaning generation, on-line discussions, learning to learn together

Collaborative constructionist activities

The idea of collaborative constructionist activities that entail discussing and sharing artefacts using computer networks or more contemporary web tools, has long been raised in the constructionist community. Noss and Hoyles studied meaning making in situations where students worked in pairs talking to each other while working on a problem with one computer (1996). Resnick (1996) introduced "distributed constructionism" based on (Salmon's, 1991) "distributed cognition" to study online communities working with constructionist media. In this new paradigm, communal knowledge building constitutes the core of the community's activities and takes place as the students discuss about their constructions via emails or fora, share them (or parts of them) through web versions of microworlds and even collaborate real-time in the process of designing and creating new artefacts.

Taking the idea to the World Wide Web in the last years, several projects have supported these kinds of activities. The CoLabs Project (http://matchsz.inf.elte.hu/Colabs/) was launched with an aim to develop tools for supporting collaborative model building through an e-learning platform both in an asynchronous and a synchronous mode. Imagine Logo microworlds (or parts of them) created by the students could be uploaded in the CoLabs Platform to serve as resources for brainstorming or further microworld development for others and as objects of discussion in community forums. On-line game playing with browser-run Imagine Logo microworlds, where connected students could work in a shared common space as well as in private ones, was also an option in the CoLabs platform (Kalas & Winczer, 2006), allowing the creation of artefacts mutually shaped by the community of students.

The Weblabs Project (http://www.lkl.ac.uk/kscope/weblabs/index.htm) also focused on building a web-based system (WebReports) for collaborating, co-constructing and thinking about models the students shared within the community of users (Noss, 2004). The models were created in ToonTalk (Kahn, 2004), a programmable environment in which the students, acting as avatars in a virtual world, operate animated cartoon characters of the microworlds like robots, birds and helicopters. In the WebReports system, the students, apart from sharing their ideas, describing in a textual form and discussing their experiences with their individual or group work in the microworld, could also share animated ToonTalk models, bringing into the core of the activity the question "how does this model" works. The co-construction of models came as the students reported on the their mathematical understandings in the process of training their robots to carry out specific actions, discussed and argued about their validity, reflected on their emerging mathematical ideas and redesigned their constructions.

In these cases students' constructionist activities embedded the "social" aspects of learning that emerged from community work. The students collaborated to shape a common artefact by discussing about it, sharing and customizing it. Working in a group, however, poses new challenges and potentials for learning. Issues of "how are we getting on as a group", "what are the roles", "what are we achieving as a whole" influence understandings and progress. Let us call these issues "socio-metacognitive" in that they refer to how students not only engage in collaboratively generating meanings about mathematics and science concepts, but also engage in learning how to learn together, in learning how to learn with and from each other as they work in groups to address challenging problematic situations in science and mathematics.

The Metafora Project views computer-supported learning in groups as a complex task that requires from students as they collaborate to also become aware of elements considered to be important for successful learning in collectives and to learn how to put those elements in use (Wegerif & Yang, 2011). When working in a collective task, the group members need to be able to show distributed leadership, planning and coordinating the tasks each member needs to carry out, motivate one another, ensure engagement for everyone (or react when this doesn't happen), reflect on the quality of the work delivered at an individual and collective level through peer reviewing, deal with constructive criticism, reflect on the overall direction of their work (devising help-asking and help-seeking strategies when needed), and make sure all group members are doing what is expected from them (Wegerif et al., 2012). All those elements constitute the key components of the "learning to learn together – L2L2" pedagogical approach adopted by the project. A web-based system that includes a planning, a discussion tool and a set of microworlds-was being developed at the time of writing with the intend to raise students' awareness in the process of learning together when working in groups and to facilitate them in putting to use their understandings of the key components of learning together.

In this paper we discuss a mathematical group activity with a half-baked microworld in a 3D version of Turtleworlds, our own Turtle Geometry medium integrating dynamic manipulation-execution of variable procedure values (Kynigos, 2007). We called the microworld the "Twisted Rectangle". Students were given a buggy procedure to construct a rectangle where one of its segments twists along a plane vertical to the one it belongs to when it's not twisted.

Such buggy procedures are given to students as half-baked microworlds in the sense that they potentially construct something interesting but are incomplete or faulty by design. The point is to invite students to deconstruct them, build on their parts, customize and change them in a personally meaningful to them way, engaging in the way in meaning-making processes. These microworlds have been perceived as 'boundary objects' (Kynigos, 2007) i.e. questionable and improvable objects engaging members of different communities in meaning making emerging from the joint de-bugging effort. They may operate as a tool of communication, around which, the members of the community structure their activities. Thus, in this case, the meanings generation processes are considered to emerge and be shaped both by the students' mathematical activity as they interact with the half-baked microworld and their social activity as they discuss on how to change and customize it.

So, we studied middle school students' interactions with the "Twisted Rectangle" microworld (TwR), focusing on their on-line discussions, as they tinker and try to fix it and as they subsequently (after fixing it) create funky constructions using the correct TwR as a base. We put emphasis on how the students' actions within the microworld were specifically shaped by their need to articulate their own ideas to others and by the ideas brought at the table by other group members. Moving between on-line group discussions and microworld actions, we seek to identify L2L2 skills such as organizing and coordinating the work so as to proceed as a group, discussing and evaluate findings from others, reflect on own findings, devise help seeking and help offering strategies.

The Digital Tools

The 3d Math Authoring Tool

The "3d Math" Authoring Tool (http://etl.ppp.uoa.gr/malt) is the latest web-based version of MaLT, built with Unity 3D a multiuser web gaming engine. MaLT is a 3D version of Turtleworlds, our own Logo-based Turtle Geometry medium. It integrates dynamic manipulation of variable procedure values so that the effect is like a Dynamic Geometry System as a value or combination of values change (Kynigos & Psycharis, 2003). MaLT allows the creation, exploration and dynamic manipulation of 3d geometrical objects, graphically represented inside a 3d virtual space.

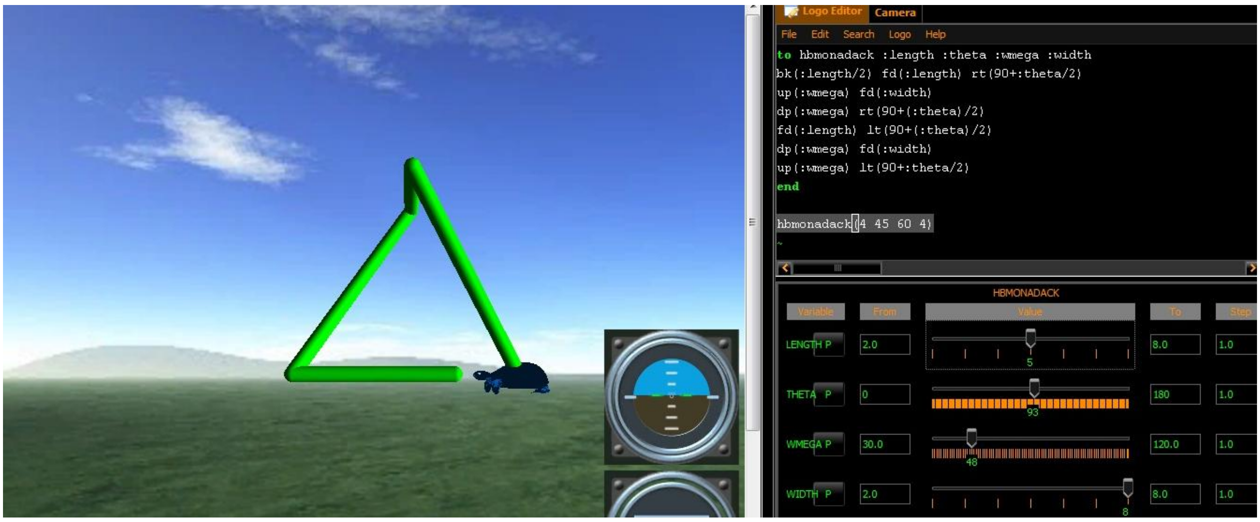


Figure 1: The Twisted Rectangle half-baked microworld

Building and manipulating geometrical objects in the 3d Mathematics Authoring Tool, however, is not restricted to solely looking at the 3d world form static 2d orthographic views. A 3d Camera Controller gives students the opportunity to navigate around, inside and through their constructions, offering the potential for new ways of visualizing 3d space and conceptualizing mathematical notions, especially ones related to stereometry (Latsi & Kynigos, 2012; Moustaki & Kynigos, 2010). We view 3d Math as an authoring tool for developing half-baked microworlds (Kynigos, 2007), such as the "Twisted Rectangle" (Figure 1).

The Metafora System

Being a completely web-based environment, 3d math is fully embedded in the Metafora System (Dragon et al., submitted). Metafora System is an on-line software platform that offers a set of microworlds for exploring genuinely challenging problematic situations in science and mathematics and shared workspaces, within which the students may discuss their ideas, argue, negotiate and engage in joint decision-making processes.

One of those shared workspaces is the Planning Tool. Within the Planning Tool, the students working together, form a common Plan depicting the course of action they should take so as to explore and address the problematic situation at hand. Assigning roles to the group members and allocating tasks is also part of the Plan to be created, as the students need to think as well about the way they should collaborate to reach their mutual goal. To form their Plan, the members of the group select and place on the shared workspace cards that correspond to Activity Stages, Activity Processes, Roles and Attitudes.

The other shared workspace is LASAD, a Discussion Tool that allows communication among individuals or groups of students. The members of the group place in LASAD's UI text boxes with their ideas (we call those "contributions") and link them with existing ones, forming in this way a kind of discussion map (Figure 3). Different types of pre-defined contributions are available and the students choose which one to insert from the available library. To further tag each contribution with respect to its content (e.g. tag a contribution as "a suggestion" or as "a claim"), a dropdown list is available in each text box. Thus, the LASAD Discussion Tool may also serve as reflection space for the students, as when they make public an idea, they also need to be explicit about what is that this idea brings to the discussion that takes place.

Research design and methodology

Our research approach was based on the idea of studying learning in authentic settings through "design experiments" (Cobb et al. 2003). "Design experiments" aim to contribute to the development of grounded theories on "how learning works" and are conducted with the intention to shed light on the relationships between the material designed for the experiment (usually innovative technological artefacts having added pedagogical value) and the learning processes within a specific context of implementation.

Context and participants

The Study described in this paper took place in a Lower Secondary Education School in Athens (1st Experimental Middle School of Athens) with ten 9th grade students (14 years old). The students worked together at the school's lab for 13 Sessions (26 school hours) in two Groups. Group A consisted of three Subgroups and Group B of two Subgroups of two students each. Each duet of students shared the same PC and used the LASAD Discussion Tool when working on-line with the microworld and with the Planning Tool so as to communicate thoughts and ideas across the different Subgroups. The Groups communicated with each other in face to face meetings.

The Educational Technology Lab (ETL) researchers, adopting a "participant observation" methodology, chose not to intervene in the experimentation so as to give out specific instructions or provide the "correct answer" to the students on how to address the challenge and proceed. They preferred to pose meaningful -often intriguing- questions at certain time points, so as to encourage students to continue their explorations, elaborate more on their thoughts, share and discuss their ideas collaborating with the other students.

Tools and Tasks

Phase 1: The Twisted Rectangle microworld

For this Study, we designed a half-baked microworld (Kynigos, 2007), called the "Twisted Rectangle". The Twisted Rectangle is a skewed quadrilateral as one of its segments twists along a plane vertical to the one it belongs to when it's not twisted. Running, however, the Logo program in this microworld, the figure depicted on screen is not a closed, but an open one, as the end of one of the rectangle's sides, is not attached to the rest of the shape (Figure 1). The students working in two Subgroups of two students each, were asked to try to "make the shape close". Being a half-baked microworld (Kynigos, 2007), the "Twisted Rectangle" that invites students to deconstruct its parts so as to make sense of what causes the "buggy behaviour". As we didn't intend to provide any answers on how to achieve this goal, but ask students to discuss their ideas in an inter and intra Subgroup mode, we had already prepared a discussion space in LASAD in which the Subgroups could meet and share their findings as they explored this issue within the Twisted Rectangle microworld.

Phase 2: Constructions with the Twisted Rectangle as a building block

At this phase of the Study, we asked the students to create their own constructions using the closed Twisted Rectangle as a building block. The students working in Subgroups were expected to discuss their ideas and share Logo code or parts of their constructions so as to create meaningful for them complicated artefacts.

Data collection-Method of analysis

A screen-capture software (HyperCam2) was used to record students' interactions the Metafora Tools, together with their verbal interactions. Since previous work with 3d Math had shown an extensive use of gestures as means to explain and communicate turtle movements and turns, a Camera was added to record students' hand and body movements. The corpus data is completed by the students' LASAD and Planning Tool maps and the Researchers' Fields notes. The video-recorded data from the screen-capture software were verbatim transcribed, while the rest of the data were used for providing additional details. In analysing the data, we searched for verbal exchanges between the students and interactions with 3d Math and LASAD that indicated that learning to learn together aspects were brought forth as they students attempted to address the challenge when working with the half-baked microworld.

Results

The episodes of this section are selected so as to highlight the students' interactions and describe: 1) the intra-Subgroup discussions as the students explored their ideas in the "Twisted Rectangle" microworld and 2) the inter-Subgroup discussions in LASAD around their findings. We draw our attention, however, on how the students' actions within the microworld are specifically fuelled: a) by the fact that they need to articulate their own ideas in LASAD and explain them to the other Subgroup as explicitly as possible and b) by the fact that they are receiving an idea from the other

Subgroup which they need to try out and decide on its feasibility and usefulness in the process of closing the figure in the "Twisted Rectangle" microworld. The episodes described in this section start with students viewing the Plan they have created at the Planning Tool.

Enacting the "Discuss Findings" Activity Stage – Planning Tool (Figure 2)

The students of Group A have created a common Plan on how to address the challenge of closing the Twisted Rectangle. Having "Formed the Hypotheses" to test and having spent quite sometime "Experimenting" working with the microworld separated in two Subgroups ("exploring questions" and "gathering information according to their observations"), the students of Group A reach the point at which they need to "Discuss their findings" (Figure 2). To enact this Activity Stage of their Plan, the two Subgroups of Group A move to LASAD to share the ideas, "observations" and "conclusions" coming from their explorations with the microworld.

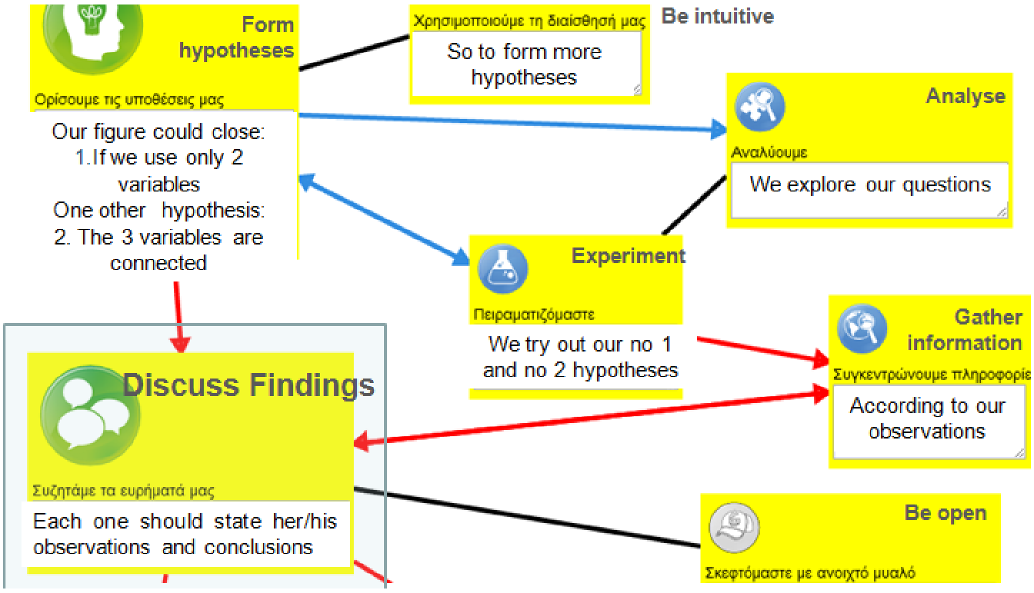
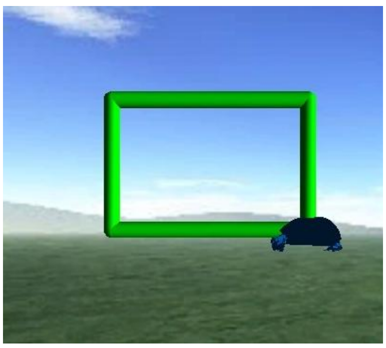


Figure 2: Part of the Plan the students have created to address the challenge

Trying to close the Twisted Rectangle - 3d Math

The students of Subgroup No1 have made several attempts to close the figure, mainly by manipulating the sliders and replacing the initial Logo program's variables with specific values. The idea they come up with is that "no matter if we change the length of the Twisted Rectangle's sides, the shape will always close if "wmega" is equal to 90 and "theta" is equal to zero". Being sure about this idea, they decide to share it with Subgroup No2 and start typing it in LASAD (Contribution no2 – Figure 3). Writing it down, however, and talking about the exact wording to use, one of the students seems to express second thoughts on the validity of this idea. As the shape that appears on the screen looks like a 2d rectangle, she points out that they haven't really addressed the problem in all cases, but have managed to just close the shape in a particular situation.



Comparing the shape that appears on the screen with the Twisted Rectangle (Figure 1), the students come to the conclusion that what makes the shape being a 2d one, is the fact that two of triangles that appeared on the initial shape were either eliminated or turned to right. This also changed tangent, cosine and sine values that should be relevant to creating the correct triangles so as to close the shape. This final idea, although not implemented or fully explored, is also added in LASAD by Subgroup No1 (Contribution no2 – Figure 3).

Sharing strategies - Communicating through LASAD (Figure 3)

The students of Subgroup No2, after asking Subgroup No1 for further information on how to implement their idea (Contribution no3), they go back to 3d math to test it for its feasibility and validity. What bothers them is that the shape generated with theta equal to 0 is a 2d one (Contribution no10), and express strong objections on if and how Subgroup No1's idea could help the Group in achieving the common goal of closing the Twisted Rectangle. The do try it out, however, in 3d math also taking into consideration the explanations the students of Subgroup No1 give as they pursue and try to refine their idea within their microworld. The students of Subgroup No1 work with the 2d rectangle (which they believe is a special case of the Twisted) and try to identify triangles (right ones as the shape is a rectangle), that could help them in defining relationships between the shape's angles and the side lengths (Contribution no14).

The outcome of this process is for the students of Subgroup No2 to move one step further. They claim that what makes the figure "non-square" or "non-uniform" in general, is the value attributed each time to the theta angle. Furthermore, they suggest that "theta" is not a visible angle (e.g. an angle between two of the Rectangle's sides), but one that is between one of the sides and some auxiliary line they need to draw (Contribution no15). As this angle is not visible, the students of Subgroup No2, decide that the best way to show Subgroup No1 this finding is to meet face to face.

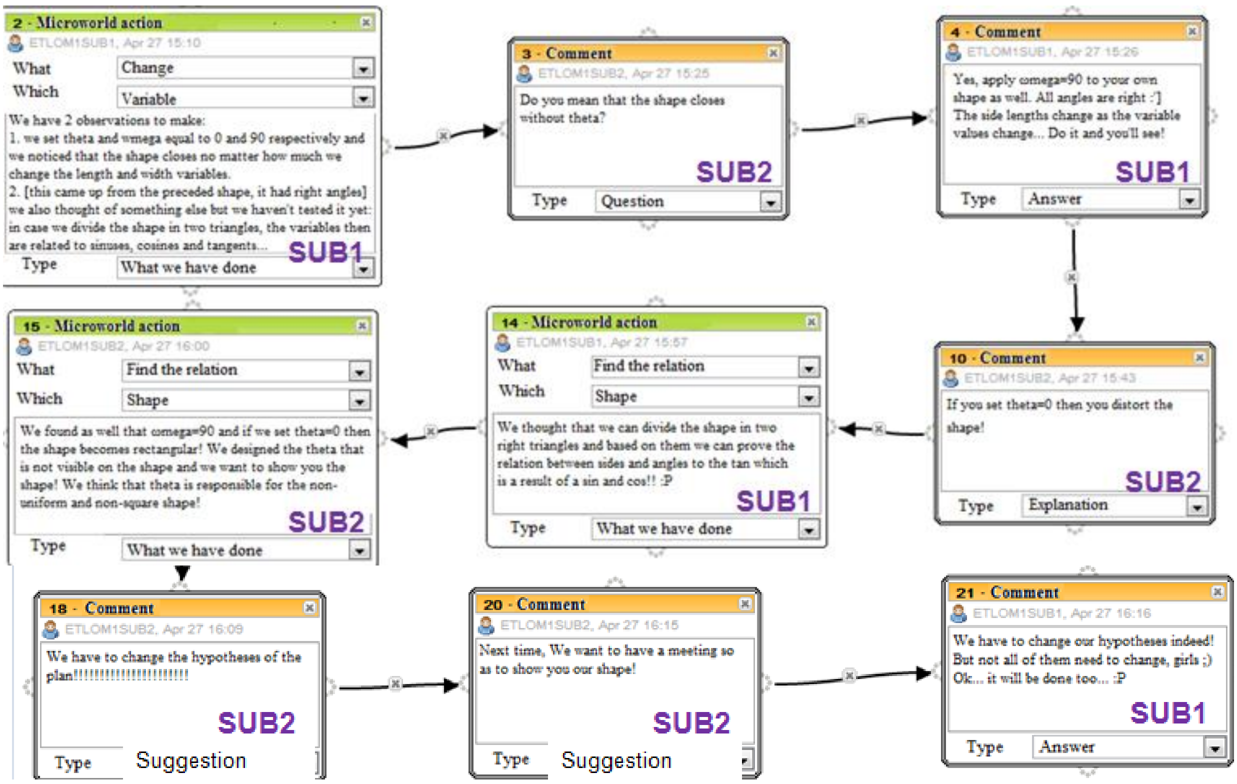


Figure 3: Subgroup No1 and Subgroup No2 discuss around their strategies on how to close the TwR

The students of Subgroup No1 receiving Contribution no 15 from Subgroup No2, move to 3d math and try to verify if “theta” causes this “non-uniformity”. They giving a constant value to the “wmega” variable and manipulate the “theta” slider to attribute it different values.

As the hypotheses they had come up with originally in the Plan they had created (Figure 2), seem to be quite obsolete now, both Subgroups agree that they need to revisit their hypotheses and update them according to their new findings with in 3d math (Contributions no18, 20 and 21).

Creating their own constructions using Twisted Rectangle as a building block

The students of both Subgroups after managing to close the figure (the students of Subgroup No2 do it first and explain Subgroup No1 the strategy they followed), they both attempt to use the closed Twisted Rectangle as a building block to create their own artefacts.

Subgroup No1 works with creating a “flower” made up of Twisted Rectangles. Each Twisted Rectangle is created by placing the Turtle in a specific location in 3d space and turning it an amount of degrees with respect to the previous Twisted Rectangle. The number of times to repeat the Twisted Rectangle so as to create the flower’s petals is defined by a variable.

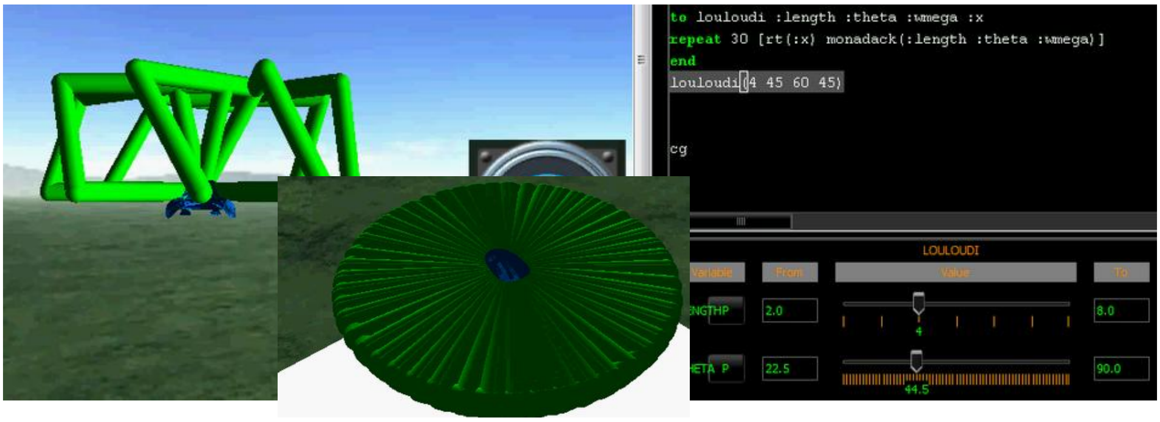
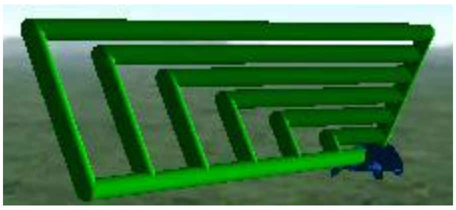
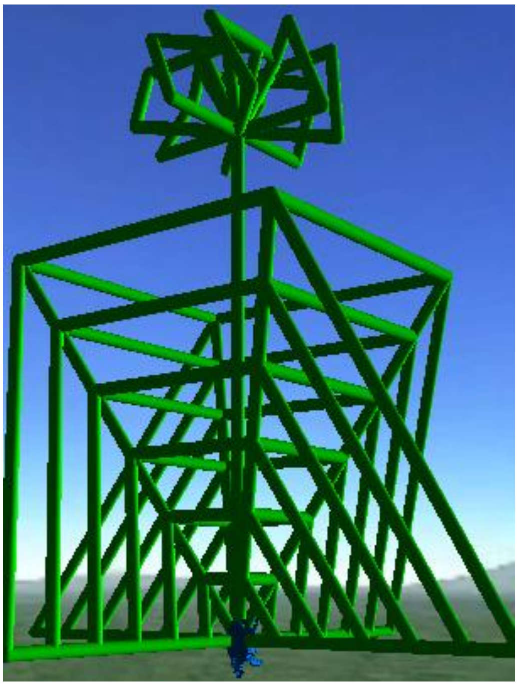


Figure 4: Subgroup No1’s “Flower” using the Twisted Rectangle as a building block

The students of this Subgroup notify the students of Subgroup No2 about their construction and share through LASAD the Logo code of the “flower” procedure. The students of Subgroup No2 have been working on a construction that includes several Twisted Rectangles all starting from the same point in 3d space but having different sizes (*Figure on the left*). That gives the impression the one Twisted Rectangle is situated inside the other.





Receiving the Logo code from Subgroup No1, the students of Subgroup No2 create a new Logo procedure that includes their own construction, which is turned to a “vase”, and the “flower” procedure. This new construction is called “flower with a stem” (*Figure on the right*). The original “flower” procedure is used, however, by Subgroup No2 with constant values, instead of variables. This causes Subgroup No1’s reaction, as soon as Subgroup No2 makes the new “flower with a stem" procedure public through LASAD. The students of Subgroup No1 create another procedure, called "the great flower", in which they use two of the procedures that Subgroup No2 has created and included in the "flower with a stem" as well as the "flower" procedure with variables instead of constant values.

Discussion

The students of Subgroup No1 and Subgroup No2 are both given the Twisted Rectangle half-baked microworld and are asked to make the open 3d figure a closed one. The two Subgroups work independently with the microworld but share mutual workspaces in the METAFORA Platform. They use the Planning Tool to create a Plan to define the course of action to be taken so as to achieve this common goal as one Group and LASAD to discuss their ideas around their 3d math explorations. Taking a close look at the students' moves between their microworld, their LASAD discussion map and their Plan, we seek to identify L2L2 elements that may influence the students' meaning generation processes within the microworld. Our focus is not only in their actions with the tools (microworld, LASAD, Planning Tool) per se but also on their within Subgroup discussions as they decide which actions to carry out in these tools.

Our findings indicate that the meaning generation processes within the microworld are fuelled by the dialogue between the two Subgroups in the LASAD tool. This dialogue is sustained by the fact that the students constantly move between their discussion map and their microworld, trying out ideas and making them objects of discussion and reflection both for themselves and for the students of the other Subgroup. Each time a new idea towards achieving the common goal (closing the figure) is proposed by a Subgroup, the members of the other one try it out so as to evaluate and check it for its usability with respect to the Group's goal. At the same time, the members of the Subgroup initially suggesting the idea, revisit it and come to reflect on it so as to make it more explicit for the others (which demand explanations if they feel that they don't understand the details). In the case of Subgroup No1, this resulted in extending the original idea, offering new insights on how to implement it. Reflecting on both approaches (their own and the one offered by the students of the other Subgroup), the two Subgroups come to put their ideas not only under peer assessment processes but also under self-assessment processes.

Subgroup No2, being proactive, use the feedback and experience from their own and the other Subgroup's explorations and taking control of their learning as a Group, decide that they need to meet face to face so as to explain to the others where "theta" angle is. As they had drawn an auxiliary line on paper, they feel they can't easily explain to the others how to do it on-line and decide to ask for a face to face meeting. In the same meeting, both Subgroups decide they need to revisit the original hypotheses they had made and report in their Plan the results of their try outs with 3d math. It seems that both Subgroups suggest that in order to proceed with their explorations as a Group (and thus engage in further meaning making processes), they need to share their understandings about the theta angle and redesign their course of action according to their up-to-that-point findings. Meaning generation, in this case, is fuelled by the fact that the students evaluate and monitor the progress they have made as a Group towards the common goal, assess specific learning outcomes as important for the Group's understandings and re-organise and re-plan the course of action to be taken so as to coordinate their further explorations with 3d Math.

The last part of the Results refers to students' constructions using the Twisted Rectangle as a building block. The students work in Subgroups without initially having a common goal which they need to achieve as one Group. Having worked, however, together to make sense of the

Twisted Rectangle's properties, they continue acting as one Group. Apart from ideas, in this phase of their experimentations, the students make object of reflection among the members of the Group also tangible constructions, which they share through LASAD in the form of Logo programs. The students exchange Logo codes and integrate the ones they receive in their own constructions. Meaning generation, in this case, is influenced by the fact that the students have integrated "sharing ideas and artefacts" within a Group as a "way of acting" for progressing the Group's work and learning.

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Representational systems on 3d navigation process

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Abstract

Twenty four 10th Grade students participated in a constructivist teaching experiment, the aim of which was to engage children with concepts related to the two systems of reference used to navigate in 3d space, geographical and spherical coordinates, as well as with the relationship between them. The result showed the utilization of the new representations provided by dynamic digital media such as Cruislet provide a challenging learning context where different mathematical concepts and abilities are embedded and interconnected. Moreover the half-baked microworld approach in activity design, seemed to engaged students in the process of instrumentation and instrumentalization by exploiting the rules of the provided game and then by setting their own rules resulting on the development of new games.

Keywords

navigation, mathematics, geographical coordinates, spherical coordinates, half-baked games

A number of research studies focused on the design of exploratory media based on the principle of integrated and interdependent mathematical representations. Kynigos (2001) introduce the term of half-baked microworlds defining the microwords that are designed for instrumentalization through constructionist activity, i.e. they incorporate an interesting idea but at the same time invite changes to their functionalities and are mediated to the targeted users as unfinished artefacts which need their input. With respect to mathematical content, the approach is to identify conceptual fields (Vergnaud, 1991) which with the use of this kind of media become rich in the potential to generate mathematical meanings, irrespective of the ways in which they might be structured (or fragmented) in the mathematics curricula.

In the design of such kind of microworlds, the principle of providing students with mathematizing activities seems to be effective. Keisoglou and Kynigos (2006), focusing on the meanings that students formed during the mathematization of a science-like measurement activity point out the potential role of the students' involvement in problem situations that are experientially real. The idea of mathematization activity involve the students' engagment in a particular real problem within the context of a microworld designed for instrumentalization. Experimenting, constructing classifications, making and verifying conjectures , generalisations and formalizations are a number of activities that should lead to mathematisation.

The 'Cruislet' environment is a state-of-the-art dynamic digital artefact that has been designed and developed within the ReMath project. It is a digital medium based on GIS (Geographic Information Systems) technology that incorporates a Logo programming language. Cruislet was conceived as a digital medium for mathematically driven navigations in virtual 3-d geographical spaces. Users can view avatar positions and define their displacements by employing either a

Cartesian lat-long-height system or a vector-differential (φ,θ,ρ) system where ρ is the length of the vector of displacement. The Logo programmability is considered necessary as it provides users with the option to actually anticipate the result of their action and engage in expression of mathematical ideas through meaningful formalism by means of programming. In this sense, Cruislet can be conceived as a constructionist medium (Kafai & Resnick, 1996) in that the user can construct flights and build dependency between flights.

A digital medium (an instrument) is internalised collaboratively by the students (Mariotti, 2002) while it is being changed often quite distinctly to what was designed by the researchers. Relatively, the implication of this perspective is that students' expressions can gain mathematical legitimacy, even if they differ from and/or they are shaped and structured by the artifact in ways that lead them to diverge from curriculum mathematics. This kind of constructionist environments provides dynamic visual means that support immediate visualization of multiple linked representations (Kaput, 1992). The key point here is that students can build their models into the medium that can act as a support for developing new meanings by investigating their hypothesis and argumentation in social contexts.

Our approach to learning promotes investigation through the design of activities that offer a research framework to investigate purposeful ways that allow children to appreciate the utility of mathematical ideas (Ainley & Pratt, 2002). In this context, our approach is to design tasks for either exclusively mathematical activities or multi-domain projects containing a mathematical element within the theme which can be considered as marginalized or obscure within the official mathematics curriculum (Yiannoutsou & Kynigos, 2004).

We adopted the approach of students' gradual mathematization within game-like activities in problem situations that are experientially relevant to students. Hence, our intention was to involve students in activities through which they would use symbols, make and verify hypotheses in order to solve a particular real problem in a rich collaborative learning environment. Within the framework of instrumental genesis, we particularly focus on instrumentalization, i.e. the ways in which students learn through making changes to the digital artefact at hand. We studied the idea of pedagogical design of artefacts so that students would inevitably poke, tweak and make changes to their functionalities as part of their mathematizations. Consequently, we saw a helpful relevance in studying mathematizations in a constructionist environment as path towards clarifying the idea of instrumentalization by design.

The focus of this study is on the kind of choices do students make between spherical and geographical coordinate systems while navigating in geographical space. Specifically, we will try to investigate how students realise the role of the different representational systems on 3d navigation process and what kind of relationships they build between them.

The Cruislet environment

Cruislet constitutes a new digital medium within the context of more than a decade of ETL R&D work on designing constructionist exploratory media based on the principle of integrated and interdependent mathematical representations. The constructionist environments designed at ETL provide dynamic visual means that support immediate visualization of multiple linked representations (i.e. any action carried on a specific representation provides immediate change and feedback in all representations, Kaput, 1992). In such settings learners are engaged in constructing public entities (constructions) implying an explicit appreciation of the relationships between mathematical objects within any situation (i.e. a mathematical model of the situation). In the case of Cruislet, learner constructions are avatar trips as well as the rules of displacement. The mathematics are those underlying the use of analytic and/or vector-differential geometry, including functions, co-variation and rate of change. However, these mathematics are integrated with geo-spatial representations and information, providing opportunities for processes of mathematisation of geographical space.

A key feature of the approach of ETL is to design artifacts afforded with integrated representations. As an example, in the last decade ETL has been involved in the design of E-slate, an educational authoring system with which many different microworlds have been developed for mathematics and science. These microworlds can be characterized as hybrids between symbolic programming (such as Logo-based Turtle Geometry), dynamic manipulation (such as Dynamic Geometry Environments), simulations, information handling and geographical systems.

In designing Cruislet we wanted to integrate programming, mathematical and geographical concepts, relations and representations (figure 1).

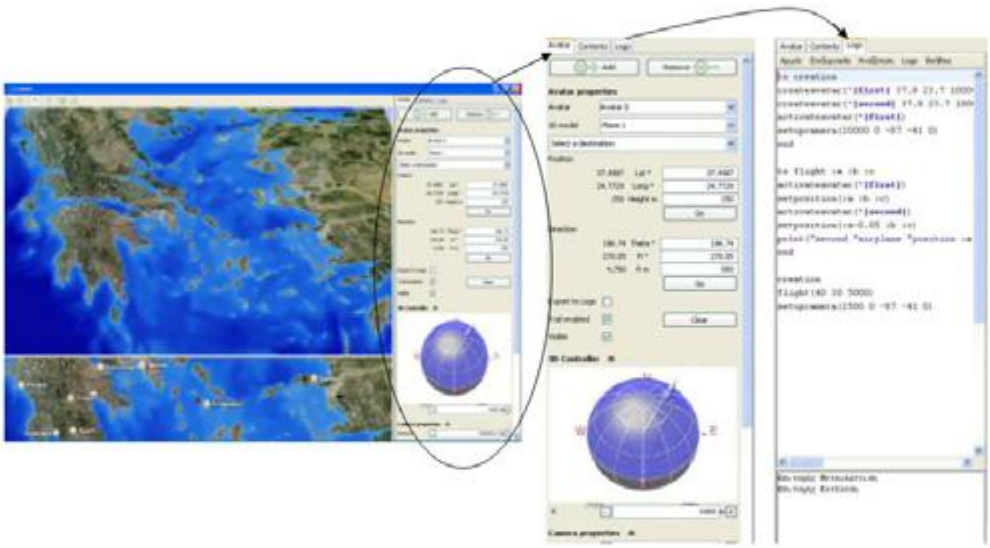

Figure 1: Cruislet environment – Avatar Tab – Logo Tab

New representations enabled by digital media can place spatial visualization concepts in a central role for both controlling and measuring the behaviours of objects and entities in virtual 3d environments. We have chosen the notion of vector as a means to represent the link between 2d and 3d representations, since vectors can be considered as basic components underpinning the study of geometry and motion in space facilitating the study of 3d spatial thinking. In Cruislet, a vector-differential geometrical system co-exists with a Cartesian-geographical one in an inter-dependent way. Our perspective is centered on the utilization of the different representations and the feedback that they can provide so as to facilitate multiple didactical decisions within open-ended exploratory tasks.

Moreover, navigations in virtual 3d geographical spaces within Cruislet could be conceived as game play simulations. There is a growing interest about the ways in which game–based learning environments facilitate new ways of learning (Gee, 2003). The key feature of this approach is that games can provide a context for the development of valuable skills (Kirriemuir and McFarlane et al., 2004) in the transitional stage between intuitions (informal) and formal mathematics. Using games with an appropriate set of tasks and pedagogy, students can be engaged in exploration, problem solving, rule-based thinking and other forms of mathematical thinking (Goldstein et al, 2001; Mor et al, 2004). From this point of view, the process of building game play activities involving navigation within the 3d representational space can be seen as the design of the terrain within which instrumentation/instrumentalisation processes may take place by student's interactions with the microworld and the mathematical concepts and rules embedded in it.

Methodology

Twenty four students of the 1st grade of upper high school, (aged 15-16 years old) participated in this experiment. Students worked in pairs in the PC lab. Each pair of students worked on the tasks using Cruislet software.

The students were not accustomed in using computers for doing mathematics, but they were familiar with computers and liked using them, as almost the whole class participated in the computer class (available as a course to choose at this school level). On the other hand, concerning the concepts of geographical and spherical coordinates, none of the students had previous knowledge or experience with spherical coordinates and only four of them believed that the acquired experiences during the geography course supported their understanding of the concept of geographical coordinates. Some of the students were familiar with the basic Logo commands (movement of the turtle, such as front, right, etc.) but none of them was experienced in using programming languages. Finally, few students were familiar with map computational environments and especially with Google Earth. Nevertheless, almost all of the students were used to play computer games and most of them were familiar with 3D game environments.

Concerning the mathematical concepts that are embedded in the number of tasks in which students have been engaged, there is a considerable distance from the traditional structure of the mathematics curriculum. In a traditional mathematics class students study the concepts of Cartesian, geographical and spherical coordinate systems within abstract mathematical contexts in a rather static way. They are introduced to the concept of function through static representations provided in their textbooks without having the opportunity to manipulating or change them. Additionally, students are introduced and study the concept of vectors. (Markopoulos, Kynigos, Alexopoulou and Koukiou, 2009a;2009b)

Tasks

The tasks are based on the idea of the "Guess my function" game, in order to provoke children to discuss, compare and experiment with dependence relations such as linear functions. Emphasis has been given to build game play activities involving navigation within the 3d representational space giving distance from the traditional structure of the mathematics curriculum. The intention was to involve students in activities through which they would use symbols, make and verify hypotheses in order to solve a particular real problem in a rich learning environment.

In the tasks that were included in the teaching experiment students were encouraged to experiment with the displacements of the two airplanes by varying the geographical coordinates of their new positions. Reflecting on their actions they encouraged to explore the rate of change of these positions and formulate the function that defines this dependent relationship. This function was hidden and the students had to guess it in the first phase of the activity based on repeated moves of airplane A and observations of the relative positions and moves of airplanes A and B.

The focus is on the functional relationships between two airplanes' relative displacements. ETL researchers consider navigation as a dynamic function event. The function's independent variable is the geographical coordinates of the position of the first airplane, which students are asked to navigate, while the dependent variable is the geographical coordinates of the position of the second airplane. We consider that the exploitation of the provided linked representations (spherical and geographical coordinates), as well as the functionalities of navigating in real 3d large scale spaces could enable students to explore and build mathematical meanings of the concept of function within a meaningful context.

The data consists of audio and screen recordings as well as students' activity sheets and notes. The data was analyzed verbatim in relation to students' interaction with the environment. In our analysis, we focused on students' actions within the provided representational contexts (visual, graphical, Logo programming) and systems (geographical and spherical coordinate systems). Students reflecting on these actions expressed their ideas, construct and developed mathematical meanings. We focused on those episodes that students seemed to realise the role of the different representational systems on 3d navigation process and built relationships between them.

Results

Students' interaction with Cruislet environment engaged them with concepts related to the two systems of reference used to navigate in 3d space, geographical and spherical coordinates, as well as with the relationship between them. We endeavor to explore students' choices while using the two systems of reference and the ways these are manipulated in order to navigate in geographical space. Our analysis is based upon students' interaction with the available representations and their preference on one system vis-à-vis the other, while carrying out the tasks activities.

Although the case for students was to choose among coordinate systems, there were several times that they didn't choose one of them, but rather they tried to create links between the systems of reference, to navigate the airplane

Choice according to the way of navigating.

Regarding the way of navigation, students preferred to use geographical coordinates to specify a specific position, e.g. a city on the map, in contrast to spherical coordinates used by students to make displacements in space, independently of the destination place, such as figural formations in the air. This was observed in almost all teams, despite the fact that some of them had a strong preference to one system of reference and used it to displace the airplane. In the following episode the teacher asks the class if the 3D controller (the 3D representation of spherical coordinates) is better in any case. Most of the students support this statement in a debate about systems of reference. In the thick of the conversation a student declares that this depends on the situation. The episode is interesting as it depicts students' way of thinking when they had to choose among the available systems of reference.

R: Is Controller better in any case?

S1: Unless we want to go somewhere specific, for instance, at an airport. We won't use 3d controller.

R: Why don't we use the 3D controller to go to an airport?

S1: Because we have to go to the specific airport. If we go with3D controller, we'll go where it lands and we'll crash.

R: Nice. And how do we go to the airport?

S1: We insert its coordinates and it goes. (Meaning geographical coordinates)

A similar situation occurred while another team was trying to displace the airplane in a specific position. In this case students believed that it's difficult to manipulate the airplane with spherical coordinates and that it's 'faster' to use geographical coordinates instead.

S1: The airplane goes faster with position.

S2: Why? We didn't go with the other so as to know.

S1: Yes, but imagine. If we control it with them, we won't be able.

The episode is interesting for another reason as well, as S1 uses the word 'control' to clarify his view of spherical coordinates. This statement is indicative of students' approach, as they viewed spherical coordinates as a way to 'control' the airplane, in contrast to geographical coordinates that displace the airplane in specific places. From our point of view, we interpret this way of viewing systems of reference as an egocentric and an absolute frame of reference, as spherical coordinates has to do with the former and geographical with the later one. As a student pointed out "*The other (meaning geographical coordinates) drives you to an area. I don't believe is as much reliable as direction, because (with direction) you can do changes on your own. Insert values, change meters you want to displace or change the degrees. Anything*.". A more detailed approach is given by the students supporting their preference in spherical coordinates." *Theta and Fi is easier, because we displace the object wherever direction we want and whatever meters we want*."

As a result of students' approach of systems of reference, they used spherical coordinates when they created figural formations in the air, although this was not included in tasks activities. An interesting example is that of a team that decided to draw letters in the air using the 3D controller representation. The figure 2 shows this construction.

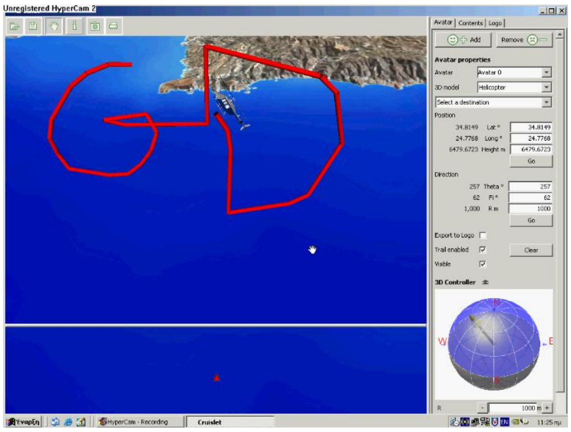

Figure 2: Construction using the 3D controller

Choice among coordinates.

In this session of analysis, we report students' choices regarding the three coordinates each system composed of and how they were manipulated in order to displace the airplane.

An interesting issue is that students confronted latitude and longitude in a different way as they manipulated height in order to specify a position in space. In particular, most of the times they edited lat and long coordinates up until the airplane was displaced to a specific point of the map and afterwards they were editing the third coordinate, the height. In fact, at their experimentation, many students forgot to edit height as they were concentrated in trying to find latitude and longitude of a place. We could say that may be this is explained by the fact that they were not familiar with the environment and thought that the environment 'reminds' previous positions or coordinates. But this is not the case as such confusion occurred only with height and not with other coordinates, even if one of them remained stable. A possible interpretation about this confusion is that students are accustomed to 2d representations where they manipulate only two magnitudes and this is the reason why they usually preferred to fly at a fixed height. On the other hand if we accept the view of Dalgarno et al. (2002) that we understand 3D models through multiple 2D representations, maybe students had focused subconsciously on a simplified 2D way of visualising the displacements of the airplanes. We have to mention that although students ignored height several times, it was height coordinate that was firstly understood.

Our findings in relation to spherical coordinates are compatible with these on geographical, in the sense that students discriminated Theta and Fi coordinates from R and additionally to the fact that they were accustomed better to the late one. This was not surprising as the measures of these coordinates are different and students identified easily what each one represented. Comparing the manipulation of these spherical to geographical coordinates, we found that in this case, students also focused on changing 2 of the three coordinates (theta, fi) in order to find the right direction. Only afterwards were they editing R, that is the extent of airplane's displacement. In fact, changes in R occurred mostly when students had already made a displacement and from the result displayed in the screen, they could estimate its magnitude easier. We could say that the utilization of R independently of the other coordinates, may rely upon the fact tha they used 3D controller representation most of the times that doesn't have the R coordinate built in.

Students didn't always choose one system of reference to navigate in space, but several times combined both to make a displacement. In this way they created links either between distributed coordinates (e.g. height of geographical and fi of spherical) or between all three of coordinates for the two systems of reference.

Links between distributed coordinates.

In their attempt to place the plane at a specific height, students used primiraly the height coordinate. However, there were some teams that were using spherical coordinates to carry out almost all displacements. Based on students actions on a team like that, students were trying to find a way to raise the airplane's height to a specific value, while utilizing the spherical coordinates. In fact one of them gave the idea to use the fi coordinate and raise the airplane by asking the other one: 'The height is fi?' and afterwards he edited the fi coordinate's value in order to raise the airplane. This statement is interesting as the student endeavor to create meaning around the fi angle that represents airplane's perpendicular angle, in relation to the height that the airplane will be placed.

Another episode where students create a link between coordinates is that of longitude and theta coordinates. In the following episode the students of a team argue about the system of refernece that displace the airplane 'right – left'.

S2: It goes right and left. (referring to longitude)

E: Right and left.

S2: Yes.

S1: No. Theta is right and left.

S2: These are the degrees.

S1: Yes, the degrees it turns to the left or right.

S2: I'm saying to displace at the same time.

The episode is interesting as it depicts the way students verbally express the way they realize the displacement while using longitude or theta angle of spherical coordinates. In both cases they use the expression 'right – left' giving the displacement a sense of direction. However, S2 supports that longitude doesn't have to do only with turning like theta, but with displacing as well. The way he externalizes his thought demonstrates that he is aware of the interdependent relationship between longitude and theta.

Links between all three coordinates

The manipulation of 3D controller acted as vehicle with which students realised the notion of vector as the displacement and associated airplanes' displacement with the variation in geographical coordinates. In this way, students explored vectors' properties as they constructed links between geographical coordinates (the variables of the vector of displacement) and the spherical coordinates. In the following episode we can see how the controller is used to identify the dependent relationship between coordinates' values. In particular, the student is using the arrow to prove the way values of geographical coordinates change relatively to the arrow movement.

R: You're saying that coordinates change. (meaning geographical coordinates)

S1: Yes

R: Increase or decrease? What happens?

S1: It depends on where the arrow's direction is. (moving the arrow of the 3D controller)

Another example of controller's utilization to create links between different coordinates, is shown in the following sequence of students' interaction with the environment, where they utilize both spherical and geographical coordinates to specify a position in space.

The sequence of students' actions indicates that they endeavour to associate the displacement in 3d space through the use of both systems of reference. Initially they use the 3d controller representation (spherical coordinates) and in this way they specify a point on the map as the geographical coordinates change simultaneously. Their second action includes the setting of one of the geographical coordinates as they want to place the airplane at a specific height on the map. In this case students utilised both Cruislet functionalities and the representations provided, as they attempted to combine the two systems of reference to displace the airplane.

An interesting dialogue that demonstrates the use of the 3D controller representation as a way of combining coordinates is the following one.

R: Why it's better? (meaning the controller)

S: Because it combines both.

R: Which?

S: Because it has, west, north and east and all these, we can do position. And because of the arrow, we can do theta and fi. In other words…

R: You confused me.

S: We can do position because of the North, South, West, East. And with the arrow, we can also do inclination.

In this dialogue S endeavor to support his statement that the 3D controller is the best representation to use. In his attempt to prove this, he is trying to correlate issues regarding both systems of reference, such as geographical directions that are represented on the sphere of the controller, with the arrow that defines the direction of the intended displacement.

Concluding, we could say that in the language of Didactical Functionalities, students' choices among the different coordinates' systems were based upon the modalities of use of the available representations built in the Cruislet.

Conclusions

Cruislet microworld is designed to provide students for instrumentalization through constructionist activity in the context of half-baked microworlds (Kynigos, 2007). In particular we use the idea of half – baked games. These are games that incorporate an interesting game idea, but they are incomplete by design in order to poke students to finish or change their rules. Thus students explored the Guess my flight game play, changed it and thus adopted both roles of player and designer of the game. From this point of view the work and play with Cruislet is based on the idea of instrumentation and instrumentalization (Guin &Trouche, 1999) since displacement rules questioned and re-defined by the students resulting in a variety of artefacts. In our analysis we focused on those incidents during the teaching experiment where students seemed to be engaged in the process of instrumentation and instrumentalization by exploiting the rules of the Guess my flight game and then by setting their own rules resulting on the development of new games.

The key point here is that students can build their models into the medium that can act as a support for developing new meanings by investigating their hypothesis and argumentation in social contexts. Displacing avatars and articulating rules of and relationships between the displacements can thus provide an action/notation context which can be a new resource for activity and construction of meanings, not so dependent on the medium for its expression. Noss and Hoyles (1996) introduced the notion of situated abstraction to describe how learners construct mathematical ideas by drawing on the linguistic and conceptual resources available for expressing them in a particular computational setting which, in turn, shapes the ways the ideas are expressed. Yet, from a social constructivist perspective, psychological and social aspects of learning can never be considered separately and the term situated abstraction captures also the synergy between them: student's activity within a community (Lave & Wenger, 1991) both shapes and is shaped by their interaction with the available tools and those around them.

From a constructionist's point of view, the functionalities of the new digital media such as Cruislet provide a challenging learning context where the different mathematical concepts and mathematical abilities are embedded and interconnected. The role of the built in Logo environment is crusial as it provides opportunities to students to express ideas in meaningful ways and in this way it can be seen as a medium in the transitional stage between intuitions and meaningful formalism. In the case of Cruislet, navigational mathematics becomes the core of the mathematical concepts that involves the geographical and spherical coordinate system interconnected with the visualization ability.

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Tinkering Creatively with Sustainability

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Abstract

Sustainability as a concept is by nature complex and elusive and therefore difficult to address. Creative thinking is thought among the core abilities needed to be fostered for developing a more integrated understanding of sustainability issues and for achieving a more sustainable world. We argue that Constructionism offers an appropriate frame of identifying and fostering creativity by viewing learning as an experiential process of collaboratively generating new ideas and meaningful digital artefacts through the active engagement with microworlds. The study reported in this paper is based on the design and implementation of a pedagogical intervention aiming to engage students in creatively tinkering with a game microworld along with the concept of sustainability. Our analysis focuses on one group of students and examines how ideas and shared understandings of sustainability emerge and evolve along with the creation of a 'sustainable city' digital game and through the students' constructive interaction with a related microworld.

Keywords

Sustainability, sustainable city, creativity, Constructionism, game design, half-baked microworlds

Dealing creatively with the 'difficult' concept of sustainability

Sustainability as a concept is by nature complex, ambiguous, context-specific and value-laden, and therefore difficult to address. Complexity stems from its multi-faceted character and the need to apply simultaneously various perspectives to grasp it holistically (Liarakou, Daskolia & Flogaitis, 2007). Alongside this there are so many suggestions of what sustainable societies should look like and what changes are needed to achieve sustainability that a great degree of uncertainty and indeterminacy is attached to defining what 'most sustainable' means (Wals, 2010a). What is also considered as sustainable now might turn out not to be in the future or it may acquire a different meaning in another context. These features render sustainability quite elusive and ambiguous as a concept and therefore 'difficult' to teach if seen through a more traditional pedagogical lens. Yet, sustainability issues are currently among the key topics of most school curricula worldwide. Teaching and learning about them is thought as a sine qua non condition for children and young people to develop a deeper understanding, a willing disposition and an action competence to identify and deal with unsustainable ways of thinking and practices and to bring change in their everyday life and the world (Scott & Gough, 2004; Jensen & Schnack, 1997).

So, how can we get students to generate meanings, develop action competence and embody appropriate mindsets around sustainability issues? In this paper, we describe our design of an intervention focused on enhancing creativity within constructionist activity, where students collectively tinker with a digital game based on the idea of sustainable city, and then we discuss our findings from studying its implementation. Creative thinking as the co-construction of new understandings and the sharing of alternative perspectives for the design and pursuit of a more sustainable world is acknowledged among those core abilities needed for better grasping the elusive and relativistic character of the concept and for achieving the goals of sustainability (Wals, 2010b). We argue that Constructionism offers an appropriate frame of teaching and learning along this line of though, by allowing the creation of shared meanings and artefacts and by facilitating discussion and negotiation over alternative conceptual suggestions of sustainability while tinkering with related microworlds.

The ambiguity characterising sustainability issues can be turned into a fruitful arena for creative constructionist activity. There is an ‘appealing vagueness’ inherent in the concept (Redclift, 1994) which makes it a ‘boundary object’ (Star & Griesemer, 1989), that is a ‘plastic’ enough entity to be interpreted and employed by more that one groups or communities in ways that make sense to them, and at the same time a ‘robust’ enough construction that manifests a common identity across all groups and communities. This approach of viewing sustainability is very close to what Meggill (1995) calls ‘heuristic relativism’, that is the recognition that there are limits in the way our perspective allows us to develop a fully-fledged view of a situation and that we need to stand off and explore others’ or alternative perspectives as complementary frames for better grasping reality. From a pedagogical point of view, dealing with ‘boundary’ concepts through a heuristic relativism frame of thinking provides many opportunities for teachers and learners to get engaged in dialogical forms of meaning-construction and perspective-sharing and to expand the ‘boundaries’ of their knowing of and being in the world. This is what some would also identify as the essence of creative thinking and learning (Fernández-Cárdenas, 2008). In either way, education has to cultivate learning approaches leading to a creative appropriation of knowledge for students to be able to develop a more integrated understanding of sustainability. It has also to foster creativity by facilitating alternative thinking and the emergence of new ideas for empowering young people to envision and design a more sustainable world (Wals, 2010a).

Recent developments in the study of creativity per se emphasize the inherent complexity of the phenomenon, the collective character of creative processes and the “situatedness” of the activities (see Daskolia, Dimos & Kampylis, 2012). Among current trends in the conceptualization of creativity is that it is not necessarily related to some exceptional ability but rather to a potential everyone is capable of displaying, which may be expressed at various manifestations of a person’s everyday life, it is fuelled by collective processes and is possible to be fostered through education. Constructionism both as an epistemology and a learning theory gives distinct emphasis to learners’ creative expression and learning through the active exploration, modification and creation of digital artefacts (Papert, 1993; Kafai & Resnick, 1996). From a constructionist perspective creativity is mainly identified with the generation of new/novel tangible output(s) (the digital artefacts). Digital media - microworlds in particular - are perceived as appropriately designed environments and tools that learners can use to construct ‘meaningful objects’ (Papert, ibid; Kynigos, 2007). These objects are the tangible outputs of their discursive, meaning-making processes while they interact with the microworlds and the learning context; they are at the same time representations of their ideas and understandings of the ‘world’. Constructionism attributes equal importance to the creative tool (the microworld), the creative product (the artefact) and the creative process of learning. Actually there is a symbiotic and synergetic relationship among the three: the microworld is designed to evolve along with the knowledge its users develop while they tinker with it and the artefacts they create.

Particular emphasis is nevertheless placed on the learning context within which both constructionist activities as processes and products occur (Resnick, 1996). Open-ended technological and learning environments that treat microworlds as 'boundary objects' and allow learners to use them in personally meaningful ways, to collaboratively work with and discuss over them and their key concepts, or to question them and want to modify and improve them, are important coordinates of a context fostering various forms of creativity. We therefore argue that the seeds already exist in the theory of Constructionism to address and study creativity through a more integrated conception, that is as a function of a *person's ability*, presuming an intentional *process*, occurring within a specific learning *environment* and entailing the generation of new *products* (Kampylis & Valtanen, 2010).

In the study reported in this paper we designed and implemented a pedagogical intervention with the aim to engage students in creatively tinkering with a game microworld along with the concept of sustainability. Our approach moves within a constructionist perspective viewing learning as an experiential process of collaboratively generating new or alternative ideas through the active engagement with the construction and de-construction of meaningful digital artefacts with the use of microworlds. In previous studies we have addressed some other parameters of a constructionist approach to teaching and learning about sustainability with game microworlds (see for example Kynigos & Daskolia, 2011). In this study we focus on the creative potential of learning about sustainability through constructionist activities.

The study

The study context and participants

The study presented in this paper is part of a design-based research which was conducted within Metafora, an EU-funded R&D project (http://www.metafora-project.org). It took place in a secondary education school located in a central area of Athens and was carried out during the last three months of the school year: it started in early March and lasted until mid June 2012. Overall, 11 two-hour sessions were held on a weekly basis. Eighteen students (9 girls and 9 boys) participated in the study. They were all members of an afternoon Environmental Education Club, a mixed-class group consisting of 7th, 8th and 9th graders. Depending on the activities participants were allocated in groups of 6 or in sub-groups of 2 to 3 students. All sessions took place in the school's computer lab and each group was assigned to a computer to work on.

The scenario and the tools employed

The students' activity was with an E-slate Microworld Kit which we called 'Sus-x', i.e. 'Sustainable-system' (http://etl.ppp.uoa.gr/_content/download/eslate_kits.htm). This is a kit allowing the teacher or student user(s) to construct a sim-city like game so that players do best when they are sensitive and thoughtful about how to ensure or promote sustainability in a particular context (system). A special case of this Microworld Kit addresses 'sustainability in the city', which is why we named it 'Sus-City'.

The Sus-City microworld allows users to create their city background map, by loading, drawing or editing their city image, and place objects on it, the city-sites they want their city to have. They have also to decide on the properties against which they will rate (give specific values to) all city-sites. A set of default (initial) values, a set of threshold values (indicating when the system's sustainability is violated by the player's choices) and the game play rules (maximum time and number of choices) have to be determined by the users. They can also inform players about their game performance through relative messages.

Based on the Sus-City microworld kit we designed a 'half-baked microworld' (Kynigos, 2007) to get students started thinking about urban sustainability and sustainable lifestyles. We deliberately called this game microworld ‘PerfectVille’ (Fig. 1) as it was purposefully designed to project an un-sustainable model of urban living, which is close to what Lange and Meyer (2009) describe as the “western new middle-class” lifestyle. This is a highly consumerist and hectic way of life which embodies the idea of ‘the welfare society’ as publicized through neo-liberal socio-economic perspectives. Its core elements, high purchasing power to satisfy individual-based needs, the pursuit of social status, high visibility and personal security and high commercialisation of quality of life are thought to be at the roots of most unsustainable practices of modern societies.

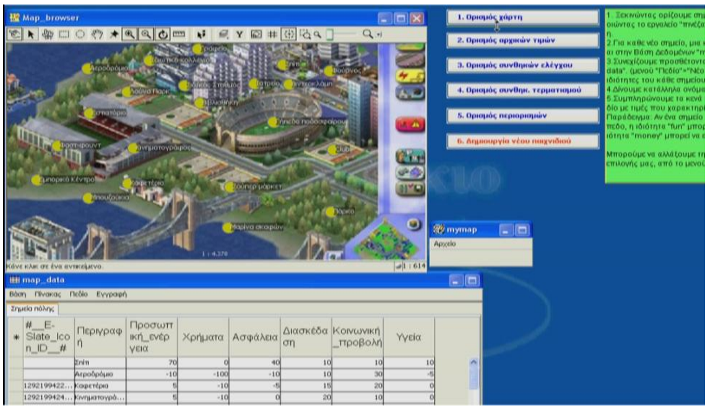

Figure 1. The PerfectVille game microworld

The students were given the challenge to play the game, discuss what’s wrong with it with respect to the sustainability of the city and then change PerfectVille into their own ‘sustainable city’ game (‘MySusCity’). This task could be carried out by a single student or group of students with the kit alone. However, in the Metafora project we have been developing a system to support learning-to-learn-together activities. The system afforded the students of the study with two more tools which were co-existent and available during their work. One was Lasad, a discussion and argumentation space, and the other a Planning tool space for collaboratively planning and reflecting on their work.

Data collection and analysis

Our analysis was based on the data collected from the 8th and 9th session of the study. Audio recording and screen capturing software was used to collect information on the students’ discursive interactions within their groups while constructing their game, and on the evolvement of their digital artifacts. These data were coupled with data from the researchers’ observation reports. All recorded data were transcribed.

We used microgenetic analysis (Siegler, 2006) to analyze how new ideas, alternative perspectives and tangible artifacts (the games) were created within the context of the discursive constructionist activity that the students were involved and as a response to their interaction with the Sus-City microworld, the challenge set to them and the researchers’ interventions in facilitating their learning. The analytical framework we employed to identify and discuss creativity is an adaptation of the categorical scheme suggested by Kampylis and Valtanen (2010). It views creativity (a) as being a function of the individual’s and group’s ability, (b) as being situated at the nexus of several interconnected processes, (c) as emerging from a facilitative learning context, and (d) as entailing the generation of new/novel abstract ideas and concrete outputs (digital artefacts).

Findings and discussion

This section presents and discusses our findings from the analysis of one case (group of students) consisting of two 13-year girls, Christina and Georgia. We provide an overview of the students' engagement with creatively constructing their knowledge about sustainability and collaboratively constructing their game. In presenting the findings we follow the four-category scheme of our analytical framework.

Creativity as a function of the individual's and group's ability

Although both girls showed an authentic interest in the task set to them and claimed an equal share in the process, their degree of involvement both in generating new ideas and constructing the game was not alike. We view this – at least to some extent – as a function of their personality and as related to their individual creative ability.

Christina has a strong personality, she is eager enough to take initiatives and contribute with fresh ideas. She is very committed to and fastidious about whatever she undertakes. She always claims a leading role in a team. During the task, Christina had a more active and imaginative participation in all stages of the design process, from the selection of the city background to setting the time frame for the game. She was also quite eloquent in expressing her ideas about sustainability and supporting them with arguments.

Georgia, on the other hand, has a milder personality. She is rather timid and usually leaves to the others both the initiative and the final decision to take. During the task she was less talkative in expressing her views and in indicating changes to the microworld. However, she tried to stay involved in almost all decisions related to design issues and to collaborate with her group mate on almost all aspects of their common work. There were moments that Georgia even surpassed herself by claiming with tenor to take control of the mouse so that she had a more direct interaction with the microworld.

Despite the individual differences in personality and creative expression we would say that some kind of complementarity was developed between the two girls with regard to their participation in the constructionist activity. We view this as an effect of the collaborative processes the two girls were involved in, upon which their group or "middle c" (Moran, 2010) creative potential was dynamically built and expressed throughout the task. This is a special case of creative ability which is fostered and revealed in shared group processes towards fulfilling a meaningful goal and characterizes the collective function of individual members.

Creativity as the nexus of several types of processes

Meaning-generation on both the idea of 'the sustainable city' and game design was evolved through the students' active display, exchange and negotiation of their ideas while they were collaboratively working on the game microworld. Actually, Sus-City offered a structured agenda for them to collaboratively propose and elaborate on their perspectives with regard to such a complex issue. In their discursive interaction and while 'tinkering with' their representations of the sustainable city, the students employed a range of cognitive strategies and communicative patterns to ascribe meaning to sustainability. Our findings indicate that there is a consecutive scalability in the students' employment of various cognitive and communicative processes that goes along with their interpretation of sustainability. These discursive meaning-making processes seem also to be in line with the students' sequential intervention on changing the various fields of the microworld (background map, city-site objects, properties, values, etc). The selected episodes presented below are indicative of this multiple 'evolution' that occurred within the context of the students' constructivist engagement.

In the first episode the group goes through the first step in constructing their game, which is to set the city background. They review a set of city-images to decide which one is closer to their idea of a more sustainable city. They observe and discern the particular features of each of them. Their argumentation is rather poor and suggestions are put forward without much justification. However, the students propose three basic features of a sustainable city, which are recurrently identified in later phases of their constructionist engagement: open green spaces, physical water recourses and less reliance in automobiles as a means of urban transport.

Christina: How do you like this one? (She shows at image no.9). Do you think it's better?
Georgia: Let's see the next one.
Christina: Wait, there're a lot of green places in this too. (They are still talking about image no.9)
Georgia: Move on…
Christina: Ok…not this one (They look at image no.15).
Georgia: Neither this one (They look at image no.2).
Christina: No…not this one (They look at image no.3).
Georgia: This one (no.6)… It has lakes too. Can you see?
Christina: Yes, but it has a lot of cars, too. Look at this…
Georgia: This city has too many cars too. (They look again at image no.9).

The second episode is taken from a subsequent phase of the students' constructionist activity. It is indicative of how their shared representation of the sustainable city has already started to 'expand'. After they have selected the city-image and changed their game's background map accordingly, the two girls focus on which new city-sites to add and where to put them on the map. This time the students get involved in more elaborated argumentation and negotiation processes over their proposed ideas. They also begin to view urban sustainability not only in terms of a "greener" or "cleaner" environment but as involving several social parameters too, such as the creation of health care services, new job opportunities and community-based organizations. They view all three of them as being in mutual dependence with a "healthier" natural environment. The economic dimension of sustainability also emerges in the students' thought about sustainability, as for example when Georgia casts the idea for an "environmental office" or when Christina suggests adding a "store selling photovoltaic systems" as a business opportunity allowing for profit and being in the benefit of the environment.

Georgia: We can place the 'health clinic' over here (she points to the city-map). Close to the park.
Christina: Yes! Cause the air is healthier over there… (They move the 'health clinic' closer to the park). What if we put an annex of the 'Scouts' organisation over here? (She points to the city-map)
Georgia: Do you think the others (the other group with whom they collaborate) will agree with this? "What do you think if we add 'Scouts' as a new point on the city-map? It is an association that helps protect the environment?" (She types a chat message to the other group).
Georgia: Let's have an 'environmental office' too.. It's an employment opportunity for the environment.
Christina: Yup, why not? Let's put it here… (She points to a particular place in the city-map).
Christina: Yes…ooh, I got an idea! Let's create a store selling photovoltaic systems. Let's put it here (She points to the map)…It's near the sea.

Creativity as emerging from a facilitating learning context

New ideas and understandings of the sustainability concept and game design emerged as a response to the learning environment created by the microworld and the teachers' role in inciting thinking on it. The following excerpt is indicative of how the teacher's (researcher's) intervention to initiate further reflection on the meaning of sustainability, by introducing a schematic representation of the sustainability concept, enhanced students' thinking (Christina's in particular) of alternative sustainability opportunities related to the citizens' sense of well-being. The teacher's intention was to provide some scaffolding to the students' thought that would help broaden their perception of sustainability from including just the natural environment. As a result Christina started identifying the 'social' dimension of sustainability in their city too:

R1: Ok girls…Can we have a closer look at this scheme? (She shows them a representation of sustainability as being at the intersection of three circles: 'environment', 'society' and 'economy'). What does it say about sustainability?... The city you designed in your game, does it pay enough attention to supporting a healthy community or a vital economy, apart from focusing only on the natural environment?
Christina: Mmm, the people… they should be happy with their life in this city… There are many facilities adding to their well-being... Such as this pool over there (she points to the map)… There is also a small port over there. People can have many nice walks in this city. They could have some nice boat trips on the river too!

The second excpert shows how the glimpse of a new perspective in viewing the city's sustainability strikes Christina as she is prompted by another researcher to review the initial values she had assigned to each of the city-sites. The researcher wanted to help the students develop a better awareness of how their game design choices can shape the players' strategies. By reviewing the 'money' values in various city-sites, Christina realises there is a lot of monetary expenditure involved while 'using' the city. For people to cherish the various goods and services provided by a city, which add to their quality of life, they have "to pay some fare" in exchange. The exception is with some public goods, such as parks. Quality of life is nevertheless very much connected to needs, and thus a highly socially-constructed concept. Such a perspective offers to the students a novel frame of approaching sustainability as a complex and value-laden issue with many interelated dimensions.

R3: So, in your game, the player has to go to work (select the 'office' city-site) twice to earn more money?
Christina: Yes, in order not to run out of their money resources… Because when visiting most of the city places you spend money. If you go to the 'bakery', you spend money…If you go to the 'supermarket', it is for buying your dairy foods… You go to the 'mall' to buy clothes, etc… To the 'clinic', you have to pay the doctors…To the 'Concert Hall', you have to pay a ticket to watch an opera…To the 'restaurant', you have to pay for the food you are served…To the 'club', you pay for your drinks…To the 'park', you… Oh no, this is one of the few places you don't have to pay anything!

Creativity as the generation of a new artifact and a new conception

Tinkering with the Sus-City microworld to construct a new 'sustainable city' game allowed students to get engaged in meaning-generation processes that led them to a better understanding of the sustainability concept along with the creation of a new artifact. The students made several modifications to PerfectVille in order to construct a new game that would better represent their idea about sustainability. Actually the new game (Fig. 2) offers a more balanced conception of sustainability compared to PerfectVille, which is leaning equally into its environmental, social and economic dimensions. More particularly:

The students altered the city background by selecting and uploading another one. Their representation of a 'sustainable city' has more green areas and other natural elements (such as a lake) intertwined in the city's fabric, less cars and a balanced interplay between more and less densely populated areas. The natural environment seems to be the dominant perspective projected in their conception of sustainability. However, the other two dimensions, economy and society, are also present in the students' discussion about the criteria for choosing this image. For example, the students justified the presence of "some skyscrapers" as indicative of the city's economic prosperity, although they would prefer they were less visible in the image. They also argued that their city offers plenty of opportunities for leading a good life. They thus identified quality of life as one of the sustainability's parameters.

The students deleted four city-sites ('football pitch', 'railway station', 'Luna-park', and 'fast-food') as not particularly contributing to the sustainability of their city. They also added eight new city-sites: 'The Scouts', 'environmental office', 'theater', 'the 'photovoltaic store', 'Hospital', 'swimming pool', 'beach', and the 'cycling path', as further enhancing the potential for developing more sustainable lifestyles. Actually, their prime criteria for constructing their sustainable city seem to be how close to their personal zone of experience the city sites are and with some of them, how much there is an obvious 'environmental-enhancing' function in them. Concerns having to do with the social and economic dimensions of sustainability were less explicit although present. The inclusion of various city-sites declares the idea of a city offering a range of opportunities for diverse groups of people to pursue a quality life according to their needs.

Among other modifications the two girls moved city-sites on the map several times so that a better matching between their function and the city image was achieved. They also re-set the default values and individual values in all city-sites with the aim to offer a more realistic evaluation of each site. Finally, they changed the threshold conditions and game play rules to render the game more challenging and thus more enjoyable for users to play.

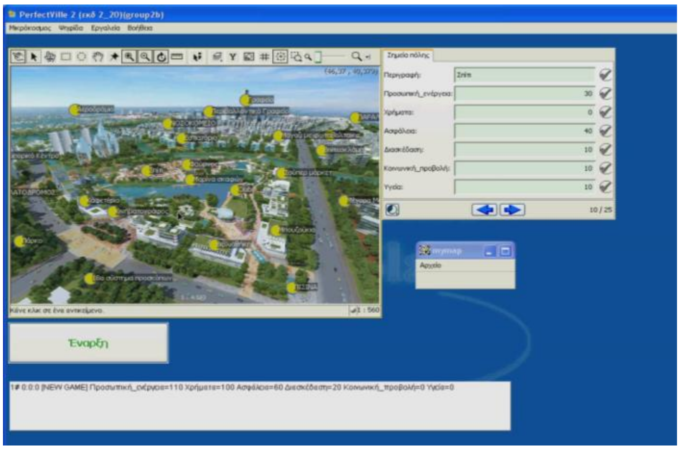

Figure 2. 'MySusCity' game microworld as created by Christina and Georgia

Concluding remarks

The study presented in this paper aimed to identify the creative potential offered by a constructionist approach to teaching and learning about sustainability. A pedagogical intervention was designed to engage Greek High school students in collaboratively tinkering with a microworld on the idea of sustainable city. Our focus was on studying whether and how creativity is a situated dimension of constructionist learning arising from the interaction of the students with a microworld and the learning environment. Our findings suggest that the Sus-City microworld empowered the students to collaboratively articulate, display, and elaborate new ideas and to develop and negotiate alternative perspectives with the view to actively interpret a complex and fuzzy concept such as that of sustainability. Actually the microworld offered not only an appropriate learning environment where students could allow their imagination to deploy and construct their game, but also a structured agenda that prompted them to collaboratively think and share their ideas about sustainability. More particularly, the students were challenged by the task set to them, to create their own 'sustainable city' game, and they were aided by the microworld to enter into intentional, shared meaning-making processes that led to the emergence of new understandings and a tangible outcome, their game. Both their discursive interaction over the meaning and features of the sustainable city, their generated ideas and the new game provide evidence of the creative potential of appropriately designed constructionist activities.

Within the context of our study we addressed creativity through a more integrated conception, that is (a) as a function of an individual's and/or group's ability, (b) as being situated at the nexus of several interconnected processes, (c) as occurring within a specific learning environment, and (d) as entailing the generation of new concepts and artefacts. Our proposed analytical framework is supported by the findings of the study. Actually we were aided to identify creativity in many more hidden dimensions of a learning situation than the obvious, and thus to expand the traditional view from within the constructionist community that connects creativity to the generation of digital artefacts only. We argue that this expanded view of the creative potential of learning situations can be of particular value for the theory of Constructionism while at the same time it can serve as a useful framework of designing and studying constructionist activities and tools with creativity in mind.

This study gives some insight of how tinkering with a microworld can allow students to enter into intentional and participative meaning-making processes that lead to the emergence of new ideas and understandings about difficult concepts, such as that of sustainability. This is of particular importance for Environmental Education and Education for Sustainable Development that are in a constant search for new theoretical approaches and tools to support learning about the complex and multifaceted nature of environmental and sustainability issues in more meaningful ways. Although preliminary empirical evidence is promising, more future research is needed as to whether and how constructionist pedagogical designs can offer appropriate modes and tools for learning about these issues. Moreover, extending constructionist frames of epistemology and learning beyond its traditional subject domains of application, such as mathematics, science and computers education, to social sciences, humanities and the arts is a major challenge yet to be undertaken. This is particularly true for educational domains that promote interdisciplinary, systemic and critical knowledge about complex concepts and issues related to contemporary realities such as those dealt within the context of Environmental Education and Education for Sustainable Development.

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Science, Education and Technology: Robotics in the curriculum at schools in Brazil

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Abstract

This paper describes, taking a PhD thesis defended in 2011, some results about the integration of robotics as a technological resource in the curriculum of a private school in Brazil. It's emphasized the pedagogical and didactical aspects and brings a discussion about teaching science and the perspective of using robotics and the relation between curriculum, science and technologies. The results indicate the integration of robotics as a technological resource in basics education in Brazil has complex aspects, such as relation between time/space, the preparation of the educators and the relation between robotics and other subjects. Therefore, the comprehension of these aspects could indicate some steps that we should think when integrate robotics into curriculum, that the technology is not going to keep the prescribed curriculum hegemony, but amplified the perspectives of education for science and technology significant and motivated for students.

Keywords

Constructionism and the curriculum; Educational Robotics; Constructionist approach; Education and Technology

Introduction

As a technological resource in education, we could say robotics has been one of the most technologies innovated nowadays. Therefore, schools in Brazil have difficulties to integrate this technology into their curriculum.

The robotics projects in basics Education in Brazil show themselves as an isolated practice in different development projects, because these projects are sometimes understand as a specific subject in the curriculum, which means it has been using in professional education in high school or college. Robotics have been seen by educators and the population as a sophisticated toy, in which people that loves robotics find themselves in championships and conferences around the world.

The research about robotics is reaching the university context – engineering and mechanics – and industries. The interest for the subject is growing, and we can see the investments from the government in education technology. Even with all the investments, only a few schools in basics education integrate educational technology subjects (as robotics) in curriculum. The more significant projects are limited in professional education and college.

Despite all that, sometimes we find educators interested in explore robotics and constructionism concepts into their practice. Influenced by researchers and primary projects using robotics in schools, by cinema and media, or by simply like technology, teachers and students mobilize themselves to construct their projects. Make the design, build, program and analyze the results of robotics become a motivated activity for the learning process and helps cognitive process

(D´ABREU, 1993), as well as provides creative activities (RESNICK, BERG e EISENBERG, 2000; RESNICK, 2006).

Today, the use of robotics in education in Brazil (from kindergarten to High school) as a technological resource receives the name of "pedagogical or educational robotics". We ask, is this the right denomination? Is it possible to determine what´s the right denomination?

The fact is we don´t want to say these nominations are wrong, but we realize educators and researchers that use this resource (robotics) with different names. We find out that even in the internet and scientific articles talk about robotics with a diversity of denominations. Because of that, we find the robotics in education researches related to the following topics:

- **Robotic object** – the concept has a direct relation with robotics hardware;
- **Physical space/laboratory** – Relation to the robotic learning environment at schools;
- **Learning environment** – Its seems to be the same as the topic before, but emphasizes the cognitive process that the environment creates, involving the space, the activities and the relations between students and the teacher;
- **Specific Project** – The characteristic is fundamental about developing projects like Summer programs, outside the school class;
- **Methodology** – This topic emphasizes the use of robotics as a methodology, in other words, pedagogical practice.

We could say that is not easy to describe correctly the name of robotics in education, if it's pedagogical or educational. But still, we don´t have pretention to defend a concept or say that one term is better than other, but we prefer to use the expression "robotics in education", because we believe robotics is a technological resource used in basics education for develop projects related to the following topics:

- Learning robotics;
- Robotics as a technological resource used in learning process of different subjects and concepts;
- Integration of both categories.

The first category corresponds to projects with purpose in learning robotics concepts, the students develop projects and learn how to program a robot, how to use a sensor and all the technology involved, and giving attention to robotics itself. At schools in Brazil, this category appears with more evidence in after school programs.

The second category, robotics are used to develop projects that holds in evidence the learning of different concepts, such as mathematics, physics, art, etc. So, this technological resource allows the school to create a different environment to the learning process, in which by creating and programming the robot, the student can learn physics, mathematics, science, arts, for example.

Although the use of robotics in the last category has a direct relation with science and mathematics, projects involved are integrated with knowledge like arts, geography, history and others, and could more interdisciplinary, in special involving the last ones.

In this point of view, the schools in Brazil work with robotics in after schools programs, specific projects such as championships during the school year and in a few institutions the projects using robotics are directly in the curriculum, in other words, are into curriculum as a subject (like mathematics, arts, history) or are used in different subjects as a technological resource, depending on the teacher.

The last category – integration – involves the other two categories, that is, the projects developed include both, learning robotics and specific topics and interdisciplinary subjects. An example of this are activities that provides learning of science concepts, and at the same time the student can construct his/her learning how to program a robot, how to use sensors and motors in the construction of the device.

Development

Our research sought, from a qualitative analysis, identify the characteristics of robotics (constructionist concepts) integration in the curriculum of a private school in Brazil, from kindergarten to high school, especially about pedagogical and administrative aspects.

When we use the term “integration in curriculum”, we refer to relation between curriculum and robotics as a technological resource, in other words, not only the use to “knowledge transmission” and the consequence adaptation of this technology to learning process, but a real rethink of pedagogical practice and other aspects that involves the integration of this resource (robotics) in curriculum.

Although we can find robotics at schools around Brazil, considering the researches produced until 2011 in Brazil, the proposes of companies that sell robotics materials and the Brazilian school system, we could say that our work has an impact in point some elements of curriculum integration of this resource and the constructionist concepts in the curriculum.

The research considered the focus group as a methodology, having sixteen students in eighth grade (13 years old). We use the data to analyze the impact of robotics and constructionist concepts in the curriculum, as the students face the subject with one class per week, studying components, sensors, engineering, math, science and others.

We accentuate that our research considered the perspective of robotics in the curriculum as an amplified form, in other words, its integration permeates the curriculum of everyday class and after school programs. However, this research prioritizes the integration of robotics in curriculum because after school programs have specific characteristics, allowing more flexibility during development. Although, this projects seems to be a part of the curriculum, with few activities during the school year.

In fact, we observe that integration of robotics in curriculum of basic education is complex, involving pedagogical and administrative aspects in relation to objectives and purpose.

It is important to point that this technological resource has characteristics that influenced directly the integration in curriculum. Robotics materials (Lego, tetrix, and picocricket) are not like computers that condense a wide range of media in one physical device, the items that define robotics demand specific knowledge (program, building, motors, sensors, etc.), which makes more difficult for teachers to know how to use in classroom for example.

There so, one important issue that interferes directly the integration of robotics and constructionist concepts is the necessity of the educational institutions to have in its staff, educators who know robotics and constructionist approach in all characteristics, such as: robotics materials available in the market, building pieces and the computer program language.

When we say educators, we are not referring to professionals specialized in computer science or robotics, which by their degree they have knowledge in program a robot and building the device, but we talk about history, arts and other subject teachers, coordinators and educational managers.

In this way we understand that education institutions, most of them, doesn´t have exclusive teachers to develop projects to integrate robotics in the curriculum, so make this process even more complex, considering the most of the teachers responsible for use robotics (constructionist approach) have their degree in science (Mathematics, physics and others).

Besides, the personnel responsible to the management (principals, advisors, coordinators) don´t have specific knowledge like teachers, which means they need to learn in service. Therefore, a few companies are specialized in courses that involve learning robotics (how to program a robot and how to use sensors, motors and a sort of pieces), so it´s more difficult to integrate robotics in curriculum.

The integration of robotics in curriculum is different from a simple specific training, demanding from teachers a continuous learning about robotics itself (sensors, motors, language program) and a pedagogical approach about using robotics in learning situations.

We can add the fact that exists in the educational market in Brazil robotics projects that seems “easy and ready” solutions for schools, with books and activities that tells everything students and teachers should do, limiting their creativity and the possibilities of knowledge construction by students. That is, robotics and constructionist concepts have been incorporated in the curriculum at schools in Brazil without a real reflection and preparation.

Another important question of robotics integration is the relation between continuous teachers learning and pedagogical planning for robotics classes, including the content and activities to be done during school year.

A relevant element of this aspect is the fact most institutions doesn´t have a consistent conceptual basis about what to teach in robotic subject, in other words, they don´t know what or how to relate any content to this technology that has been incorporated in curriculum tables, and the consequences are different ways to choose books and didactic instructions to robotic as a subject.

Indeed, this is a fundamental data when we talk about integration of robotics in curriculum. Differently from other subjects such as mathematics, history, geography, culture studies and others, those have been historically constituted in schools curriculum with defined content for all grades, robotics don´t have this structure, and for this we can see a wide range of content that is not helping the real need of robotics integration in the curriculum.

To exemplify this, we could think in schools that have an annual planning for content in robotics subject related to technology concepts directly attached to sensors, motors, cables, pieces and program, as an example, learning how to program an electronic device (robotic) and use of sensors and motors. In this case, schools cannot get together interdisciplinary subjects that compose school curriculum and either construction of scientific concepts.

Other example are institutions that gives privilege in content related to subjects in general (science, mathematics, physics), which can reach learning of technology that we mentioned before.

Well, in fact when we think in integrate robotics in the curriculum is consider the basis to choose content to work in robotic subject. Considering the results of interviews and the observation of activities during school year of 2011, we believed that integrate robotics in curriculum as a subject should be sustained in three basis: education for **science**, **technology** and **interdisciplinary**. In this particularly research, we observe physics subjects and during the activities the students amplified science and other concepts.

As an example, an 8th grade group of students had an idea to a project (The theme was about robotics and special human needs) that teacher asked them to get involved. Instead of just research and present something press, they decided to build a model of a wheel chair with lego mindstorms and also construct a small example of a street to represent a real attempt of the device they were building.

For that, they spent two months to design all. What made that possible was because they had one lego mindstorms exclusive for them, and so they could experience the whole project building and also learning the concepts involved.

Figure 1. Image of students building the street reference for the Lego model.

To compare, the same group had weekly robotic classes, in which they worked in projects design for only 50 minutes. On that, all students should build the models and at the end of the classes they get all the pieces back in the box for other students. That is different from the project we described above, because in this case they couldn't use the same Lego material for a long time. Instead, they constructed some device and had to take all the pieces apart to other students that were going after them.

Therefore, these aspects need to guide the content insert in pedagogical projects in educational institutions and the integration of this technological resource in curriculum in a significant way (Thinking about constructionist approach), having as a reference the construction of knowledge and the student's freedom in the learning process.

The education for **science** expresses elements such as investigation process and concepts like force, motion and energy. About education for **technology**, we need to consider the knowledge of pieces functions like sensors, motors, computer science and all involving this theme.

Lastly, we have education in relation to interdisciplinary, in which involves concepts such as working team, creativity and even those that are not directly attached to robotics or science. We want to say that interdisciplinary is something inevitable and goes beyond different subjects, amplifying their boundaries.

Integrate robotics in curriculum is fundamental, because it's not only a technological resource that allows students to participate directly in their learning process, but has a potential to contribute in the development of projects that aim to emancipate the students in their thinking.

Besides, contributes not only to build a multiple referenced curriculum, that considered both historically content and specific context in each institution to develop pedagogical projects, but also to enrich a culture of use of technology in education that has sustained by emancipation and autonomy of students in learning process.

It is not, therefore, simply add a subject "robotic" in curriculum because is interesting, to conquer new students or to be more "visible" with clients (in case we talk about private schools, because in Brazil is more significant in use of robotics), neither to use this technological resource in a few moments during the school year depending on the teacher or the content. (Bers, M., 2007)

Indeed, integrate robotics in curriculum means considerer two sides, articulating the teaching learning about robotics and a school pedagogical approach that has as foundation to the necessary steps to develop an activity using robotics (**challenge/problem, design/solution, test, results and share**), providing to students an active participation in the whole process.

The creativity in the context of robotics integration it is another important element. Projects that give instructions to students to build the devices don't help in knowledge construction and student autonomy, and this is the most usual scenario around the schools in Brazil.

Then, during the class steps described before (**challenge/problem, design/solution, test, results and share**) students need to be creative, in other words, they cannot, for example receive instruction (device model) to build, but instead use imagination and the challenge proposed to build their device. They have to program the device to operate and not get the program from the teacher.

A reference for creativity is the spiral of creative thinking from Resnick (2007). For this, *creativity* must permeate the student action during all steps in robotics activity, with the objective to enrich the use of this technology and constructionist concepts in learning process, and there so, guarantee the significant integration of robotics in curriculum

Another fact that compromised the integration of robotics in curriculum is the relation time/space, related to development of robotics activities in schools. The data from students shows the needs to rethink this matter.

Most of the schools don´t have specific labs to teach robotics, environment that facilitates students to be more engage during the activities, using large tables with computers and different robotics materials. What happen in some schools is that robotics classes usually occurs in small places, with association to computer labs, and students must build their device with small spaces available, interfering significantly in the integration of robotics in curriculum.

We can go further, talking about time. In general, schools have in their curriculum robotics classes with only fifty minutes, or in some institutions with one hour and a half. This context makes difficult to integrate robotics in curriculum because the lessons steps that we described cannot be fully developed. As an example, we could imagine a robotic activity, and during fifty minutes students must design and build the device, write the language program, test and share the solutions.

It is not difficult to understand that time is not sufficient, which makes the integration of robotics limited in all ways and all the steps are compromised. In case of after school programs, even though time seems to not be a problem (because the project could last weeks), the projects have been developed without connection to curriculum.

The relation between time/space is directly attached to management in institutions, because the costs involving teachers, robotics materials, classes' time and adequacy in the curriculum prevent us to reflect about our real needs to integrate robotics in curriculum.

Then we could say, the integration of robotics in curriculum is considering **education** for **science**, **technology** and **interdisciplinary** as fundamental elements to pedagogical planning for teachers and educators, especially about content of robotics.

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Towards Turing Teaching

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Abstract

The technicity thesis and its T/V concept quality division is applied to education and three modes of learning, based on the medium used, derived. The medium of the mode designated Turing, has the computer as its medium. Primary school, being both the foundation and cognitively the most complex phase of education, is considered from traditional and Turing teaching perspectives. Proto-Turing practice is exemplified. Given that current method is inefficient and abusive, and transition to Turing teaching is inevitable, an approach method development is suggested.

Keywords (style: Keywords)

Technicity, teaching, primary school, concepts, mode, medium, method,, Turing machine.

Introduction

The relationship of computer technology to teaching in schools is confused. The commonly used term “ICT” (information and communication(s) technology) has been unhelpful and was recently roundly criticised as meaningless by the Royal Society (Furber 2012). The Cambridge Review of Primary Education (Alexander 2010) also found great difficulties with this curricular area. The author has always viewed such terms as administrative language, preferring to see the computer and its associated technologies as a new teaching medium with novel capabilities. Given that this medium can also emulate extant media, a term was required that clearly specified teaching that made use of the new capabilities. Given that, conceptually, the learner is interacting with a Turing machine, the term “Turing teaching” was proposed (Ó Dúill 2011a).

When a new term is introduced it is essential to try and make its meaning is unambiguous. For Turing teaching which uses Turing media, disambiguation is achieved by reference to the concept of technicity and the two qualities of concept that flow from this neurological adaptation. Technicity as a concept has been developed in the Eurologo/constructionist community (Ó Dúill 2010), reaching its final form in a companion paper submitted to Constructionism 2012.

On this foundation a sound, scientific basis for education may be built. This includes recognition that:

- the primary phase is cognitively the most complex and that, at present, deep understanding resides only in the unarticulated expertise of the primary school teacher;
- medium and method have a specific relationship with mental processes, which determines learnability and, where concepts collide, may be a cause of cognitive confusion and conflict;
- positive affect is crucial to the educational process: dislike signals cognitive difficulties.

Three modes of education are derived from medium considerations; two extant, the third Turing. These offer a new perspective on some well known difficulties that inhibit development of both literacy and numeracy; and challenge certain strongly held views and constructivist approaches.

With these considerations in mind, the character of Turing teaching begins to emerge: working with a medium that has the capacity to be attuned to the workings of the mind and thereby offers a more conducive, less oppressive educational experience. This notwithstanding, Turing teaching has prerequisites: the basics are outlined and exemplary practice identified. These considerations throw into sharp relief the difficulties, conceptual and practical, that transition from traditional to Turing medium in (primary) school entails: a challenge not posed for over six millennia.

Technicity

The technicity thesis proposes that the human capacity for technology came about by a very small extension of connectivity between prefrontal cortex and the rest of neocortex. The evolutionary history of hominines involved a large increase if brain size, reaching a maximum of some 1400cc in the Neanderthal. A significant factor in this increase was relatively greater enlargement of the prefrontal area, which is the site of working memory and has an executive function. It is the seat of creativity, gathering information from memory (other neurone circuits) and recasting it in a process of exploring alternative plans of action. It modulates and modifies the actions of older parts of the brain. This modulation is achieved by the massive invasion of most other parts of the brain by prefrontal neurones. Note that the evolutionary process of prefrontal expansion and invasion has no teleological aspect. Neuronal expansion, like any other cellular rebalancing will become genetically fixed if and only if, post facto, it is adaptive. For neurones this means that for any expansion to become genetically fixed the information prefrontal neurones source from the rest of the brain must turn out to be useful to the organism. An extension of this invasive process to primary sensory cortex is proposed by the technicity thesis.

Information quality

Certain areas of primary sensory cortex are particularly interesting because of the quality of the information structurally embedded in their neurone circuits. Information may be incorporated in neurone circuits for two purposes: instinctive behaviour; and processing sensory information. The former has a level of complexity commensurate with the environment. The latter reflects the way the sensory system processes incoming information. This processing proceeds by reconstructing the environment from inbuilt elemental information. This is obvious once it is understood that, for example a photon reacting with a receptor in the eye results in a nerve impulse. The correct interpretation of this impulse, formally equivalent to a symbol on a Turing tape, requires the nervous system already to possess information about colour in order to match the incoming symbol and reconstitute its physical referent. Because the nervous system is built on information about properties of matter available to the genome, these computational units express genomic information; in the example, on photon frequency in the visible light range. By extending their range of information sources to primary sensory cortex, prefrontal neurones opened a window onto the information possessed by the genome, as expressed in the neural processing system. This information is simple in form and therefore of far lower entropy than the environmental input to the sense organs so, by definition, more powerful. Some of the information available at primary sensory cortex, from which technology and art are constructed, is listed in table 1.

Colour	Line	Motion	Pitch	Chemical
Pigment Art Spectrum Photons	Shapes Architecture Symbols Geometry	Projectiles Choreography Machines Entropy	Tone Music Time Relativity	Flavour Cuisine Molecules Particles

Table 1. Some sources of genomic information expressed in neurone circuits and behavioural correlates.

Note the relationship with the aspects of child development so clearly seen in kindergarten and absence of a direct link to language.

Provided that an organism can make use of this information in a way that proves to be adaptive, the genetic organisation that underpins it will be retained. It is self evident that this has proved to be so for the human technicity adaptation.

Two qualities of concept

The information available at primary sensory cortex is very simple. From the image of a tree at the eye, a complex percept is created. From simple straight lines at different angles sourced from the so-called feature detectors, a simple form like a square may be constructed. This concept may be superimposed on the environment to organise it. For example, a square may be folded from a roughly torn piece of paper. However, this form has characteristics that differ from that of a tree. A tree leaning at a forty five degree angle remains a tree. Rotate a square by the same amount and it is perceived as a different object: a diamond. This indicates that there are two routes to concept formation, leading to concepts of differing quality.

The first, characterised by the square/diamond, is the normal perceptual route. Such concepts are naively congruent with the environment, and of commensurate entropy. Expressed with language, with which they co-evolved, they are socio-perceptual. Vigotsky described this route to concept formation, including its associated internalised speech. The term V-concept is used to denote it.

The second, characterised by the ideal square, is the technicity route. In this case the information source is genomic information expressed in neural structures and directly accessed by prefrontal cognitive processes. The concepts are prefrontal creations unconnected to perception or language. The simple elements from which they constructed are of low entropy, commensurate with that in the genome, and thereby they are powerful relative to their perceptual counterparts. In describing the eponymous machine, Turing was employing this mode of conceptualisation. It is the source of troubling notions such as Platonic ideals and counterintuitive scientific theories. Derived from the technicity adaptation it is uniquely human and expressed as inspectable physical constructions. The term T-concept is used to denote it.

The crucial difference between the two is that, whilst a V-concept may be accepted because it has internal linguistic consistency, T-concepts must be shown to be consistent with the behaviour of the physical world; to which technicity uniquely provides the human with cognitive access.

Three modes of education

The technicity adaptation, though genetically inbuilt, differs from genetic predispositions such as language. Speech begins to come on stream in infancy and is learned through immersion in a language community and with caregiver tutoring. Technicity, as evidenced by drawing, begins to emerge somewhat later and is as much a personal exploration of the attributes of the medium as a means of expression. Unlike language, which is equally expressive regardless of the culture that owns it, the technological sophistication of societies has varied markedly. Thus, immersion in the domestic culture is inadequate for the effective development of technicity capability and a formal system of education becomes necessary. Based on the two qualities of concept outlined above, it is possible to derive three modes of teaching and learning.

The first mode is purely V-conceptual. It makes use of capabilities that evolved in the primate and hominine lineages and which reached their apogee in the twin species of Neanderthal and human. These are: a) spoken language communication; and b) a capacity to learn by observation from demonstration: learning by rote, repetition, reproduction, and by inner-speech rehearsal.

This mode is sufficient to conserve the knowledge base and provides a platform for some limited innovation. It was well described by Vigotsky (1962) and will be denoted by the term Vigotskian.

The second mode is technicity-based and makes use of graphic forms both to express T-concepts and to provide external memory storage. The most important innovation is the development of systems of notation that provide insight into mental processes. Written language and numerical notation are the foundation of this mode. The former is a technology that notes the grammatical and lexical aspects of speech, omitting all prosody. The latter, in its decimal place-value form represents the way humans think about number. This education system, which Alexander (2010) so fully describes, has been in use for at least five millennia. The key that unlocks access to the knowledge base is literacy and numeracy, the apprenticeship in the 3Rs that dominates current primary education practice. It is an onerous apprenticeship. Not all children master the grammar of the medium and there are collateral casualties as a consequence. This mode of schooling has a name with historical depth. The institution where the grammar is mastered is a Grammar school.

The third mode, the subject of this paper, barely exists. Its medium is the Turing machine and it brings into focus those constructional aspects of education that have been relegated to technology and art in current school curricula. The Turing machine, by definition, can read, write, and, with a little instruction, do arithmetic. Represented in classrooms by a stored program digital computer, this medium has the capacity to assist children in mastering the grammar and the animation of its content. Text in this medium, which stares silently from the page of a book, may be animated in a multitude of ways. It relationship with cognitive processes differs from that of text. The medium conceptually being a Turing machine, the term Turing teaching will denote it.

Vigotskian	Grammar	Turing
Socio-verbal / observational	Textual	Computational
Shared with Neanderthal	Uniquely human	Uniquely human
No external medium	Externalised memory	Externalised processing
High memory load	Demanding apprenticeship	Assistive
Environmental entropy	Mixed entropy	Genomic entropy
V-conceptual	V/T-conceptual	T-conceptual

Table 3. Some major differences between the three modes of learning now available to the human.

The main differences between the three modes of teaching and learning: Vigotskian, Grammar and Turing, are listed in table 3.

Technicity thinking

During the primary school years children learn increasingly to apply the capabilities of technicity. Therefore the purpose of education, often defined culturally, may now be given a more species oriented perspective: the development of T-conceptual thinking. The starting point for this is the V-concepts that children bring to school (Bransford et al 2000). At present this transition begins with the literacy and numeracy. Children learn to use the power of letters, numbers and shape to bring speech and perception under T-conceptual control. An important question in terms of the need for transition to Turing teaching is, “How well does Grammar school method work?”

Literacy

At first sight it is reasonable to take spoken language as the starting point for reading and writing.

There is a problem, however. Text does not represent speech. Computer speech engineers have shown that only the lexical and grammatical aspects of speech are represented in writing and the sounds and music of speech, the prosody, is not (Taylor 2008). From a V-conceptual perspective, this is surprising. It seems obvious that alphabetic writing should represent the sounds of speech. Reflection shows this cannot be so: There are many dialects of any language and speech sounds vary enormously. Writing is a technology for noting the unvarying aspects of a given language and cannot represent such diverse pronunciations as Cockney and a Scot. This notwithstanding, Grammar schooling does elect to work from speech to writing: the phonics approach maps letter groups to the sounds of Received Pronunciation or General American. Mapping between RP or GA and text is very poor (vide dictionary pronunciation guides). Whilst most children do learn to read, the misconception that text is speech written down is a major source of spelling errors and inhibits the writing of many children and adults. Grammar schooling has no answer to this problem. Administrative and academic interventions have had minimal effect: teachers have had some six millennia to hone their technique. Put quite simply: the book is a demanding medium that offers no help to the child in decrypting and animating its contents or in creative encryption. The failure rate is high and associated with demotivation and dislike of school.

Numeracy

The number of children and adults who hate mathematics is legion. Traditional teaching takes 2 parallel approaches: a) oral, where children learn the language of number and mentally and orally to compute; and b) structural, where they count objects and measure. It seems obvious that these approaches will and do complement each other. Technicity considerations suggest other wise.

Counting is V-conceptual: a verbal-perceptual activity. Objects are counted and collected up into base-related bundles: eggs by the half dozen, Dienes blocks by tens. In the latter case connection to the fingers of two hands, which are available to mediate one-to-one correspondence, is clear.

The language of number is T-conceptual. It represents numbers in a different way and in so doing opens a window on the working of the mind. Number, though familiar in technological cultures, is not natural, humans prefer to name people and things, and number words had to be invented. The language of number appears to mirroring counting; but it does not. Language works from the absence of anything through enumerated objects up to, but not including, ten. The brain appears to have a register system, as do real (as opposed to conceptual) computers. Written language does mirror this way the mind works but place-value number systems do so with greater clarity.

The cognitive conflict between the perceptual and linguistic methods is dramatically illustrated if a chequerboard “hundred-square” is enumerated using decimal place-value numerals. The first and last lines of such a chequerboard, found in many primary schoolrooms, are shown in figure 1.

1	2	3	4	5	6	7	8	9	10
91	92	93	94	95	96	97	98	99	100

Figure 1. Segment of chequerboard hundred-square marked with decimal place-value numerals.

The cognitive conflict with language is clear: humans mentally count to nine and then increment the succeeding register by one. Place-value numeral systems are a T-conceptual technology that is representative of mental operations. Perceptual counting is V-conceptual. Here is a cause for cognitive confusion. By counting and carrying out practical activities with bundles of ten children do not come to an understanding of number, already embedded in language, rather the reverse. What they say requires unambiguous means of external verification. Sawing a unit of abacuses, colouring hundred squares, and using Dienes blocks for model-making might be a good first step.

Kitchen maths

The cognitive difficulties that underlie the failure of Turtle geometry have already been discussed (Ó Dúill 2011b). The same considerations apply to the notion of "kitchen maths" (Papert 1993,) which, noting the skill with which inumerate individuals handled quantities and proportions in cooking, sought to find a means of constructing mathematical ideas from these capabilities. This appears, in principle, to be similar to working from naïve concepts to scientific ones. However, the danger is of conflating V-conceptual thinking with the T-conceptual. The key V/T difference is that the former is derived from perception, from individual experience, and the latter is constructed from species-level information concerning properties of matter. T-concepts are superimposed on perceptual experience and not extracted from it. Whilst direct experience to develop craft skills is possible in the Vigotskian learning mode, practical experience cannot lead directly to T-conceptualisation. It is necessary for the teacher to propose such concepts for the learner to project onto their experience, i.e. the scientific method of checking against reality. Given that the V/T concept distinction was not available at the time constructionism was first proposed, some early examples of constructionist practice may require reconsideration.

Turing teaching

In childhood, Alan Turing played with Meccano, the mechanical precursor of LEGO Technic. He thereby exercised the technicity adaptation is ways that Grammar schooling did not encourage. As a consequence, his PhD on computable numbers could be based on the brilliant insight that it is not possible to divorce mathematics from the mathematician. The Turing machine, cf. Carnot's waterfall image, is based on the image of Turing himself sitting at his desk with paper, pencil and eraser. The mechanical Turing can read, write, and erase symbols on an infinite tape; the process of so doing altering the state of the machine, based on its existing state. At a stroke of his pen, the second law of thermodynamics was inserted into the field of mathematics and mathematicians. From an educational viewpoint, the computer in school is a Turing machine with the capability to read, write, and, with a little instruction, do arithmetic. This contrasts markedly with text media.

The phrase "with a little instruction" gives the clue. As Papert so rightly said many years ago and the Royal Society echoed this year, programmability is an intrinsic property of the medium. This does not imply that programming is an entrée to mathematics, as the originators of Logo claimed. It is programmable in the same sense that a surface is capable of taking a mark. Mark-making on paper is a natural childhood activity, so is talking. Writing an instruction is a combination of the two; with the possibility that the medium may respond. Programming is, therefore, no more an introduction to computer science than is the activity of drawing an introduction to architecture; and no less so. As a form of writing, there are necessary precursors to programming. It is the role of the primary phase of education to establish them in a manner congruent with its curriculum.

Primary precursors

Given that the computer is the medium of Turing teaching, it follows that mastery of the medium is the first priority. It is essential that children have one-to-one access to it. The sharing of pencils is not considered acceptable, no more so is the sharing of keyboards, screens and graphic input device. New technology is not necessary: any computer less than twelve years old is suitable.

The start is at the beginning. Primary school runs from the end of kindergarten to the secondary school. It is the foundation for all that follows. Like the foundations of a building, the remainder of education relies on its stability. Similarly, the effort that went into its construction is invisible in the final product and unconsidered in its use. A quick resume of its nature is therefore required.

A child entering the primary school years has a complete language system. Gone are the strange structures of infant speech, but discoursive speech is still to be formed. Childhood might better be called chatterhood as children exercise the prime social networking medium of their species. It is the phase where the technicity adaptation comes strongly on stream. The beginnings of are seen in the geometrical drawings and primary colourings of kindergarten. Covering classroom walls, they attest its importance. Sound making, with voice or instrument; the crude flavours of snack foods; and choreographed movement in playground games attest its emergence.

Neurologically, this is the period when prefrontal cortex establishes connections with the rest of the brain. Although the basic architecture of the nervous system is complete at birth it is pruned and tuned by experience. A) Orbitomedial fibres find their targets in the older part of the brain, so moderating and modulating affective factors such as attention, motivation and emotion. These connections are mature by the onset of puberty at the end of the primary school years. B) Lateral prefrontal cortex, which connects to neocortex and is cognitive in function, matures more slowly. The majority of connective growth takes place during the primary school years though maturation continues into tertiary education. Primary school experience is the foundation for all that follows.

Turing basics

Because the Turing medium can carry out processes, it may be tuned to the mind of the learner. Because the Turing medium can carry out processes, it may assist the user. Because the Turing medium can carry out process it can also, and currently mainly does, emulate non-Turing media. Tuning to the mind and providing assistance have little explored because both these capabilities conflict with traditional teaching method. The character of this conflict and the pressing need for its resolution may be illustrated through literacy and numeracy method. Technicity, recall, is a constructive cognitive process executed by prefrontal information gathering and composition.

Writing is a technology that notes only certain aspects of spoken language, so it is plausible that learning to read and write entails access to appropriate information in the brain rather than signal processing on perceived speech. This idea is supported by second language intelligibility studies and the sign languages of deaf people. Therefore, phonics approaches probably do not do what is claimed for them. Adults who have spelling difficulties report using a method that uses a sound model of the text. Though difficult for a human to articulate,(although children do it in the early stages of reading) this would be a trivial application within computer speech technology. It would not be an alternative accent, like RP or GA, more a parallel stream that reflected the equal weight of letters on the page and the spaces between them; and thereby more in tune with technicity. The assistive aspect comes from possibilities that the medium offers for working with text without the need manually to form letters; keyboarding as a means of playfully to investigating text's nature.

Number, as discussed above, is a conceptual mess. Turing media add in the way the mind does. It follows that playing with the symbols in the medium, not counting, is a good precursor to mathematical understanding,. There is no developmental issue in working from the symbols to physical reality. Young children exercise the ability to create geometric forms from a very early age. A written number is a shape as much as is a square or a letter; and as learnable. The problem comes in animating number/operator expressions. The textual method of Grammar schooling makes this an unnecessarily tedious exercise. As with reading, the medium is obstructive. Turing media offer a multiplicity of assistive means of entry into computation. Once learned, the symbol system may be tested against physical reality: i.e. counting comes after number is understood. Competence with symbols is the key to higher mathematics.

Medium mastery is a precondition for its effective use. This is as true of Turing media as pencil and paper. It follows that children need systematically to be taught to work with the medium from the start of formal schooling. Attainment expectations need to be determined and set. But there is a very great difference between mastery of Turing media and mastery of text media. The medium has the capacity to assist in the process of its mastery. Thus, instead of tedious practice exercises children may create from the outset. This enables a graded project-oriented approach to be used. Such and approach was developed in Bulgaria by a primary school teacher, has been reported to a number of Eurologo conferences, and is sanctioned for use in primary schools in that country and Macedonia (Ilieva 2010). It comprises a suite of small programs called “ToolKID”, written in Comenius Logo, that cover all the possibilities of working with the computer through a project oriented approach based on the normal activities for the age of the children (fig.2). In addition to this introductory software, the curriculum included the option to work with external devices. This introduced the principles of computer control and Logo programming in a context that reflected the children’s knowledge of their world using the language and writing skills they were learning. Additionally, this approach greatly emphasised the aesthetic aspects of constructional activity.

A five-year-old who today began to follow this exemplary curriculum would six years later enter secondary education with new capability. Secondary education would then have the challenge of new child competences, for example a child whose writing fluently flows from fingers to screen without a glance at the keyboard; and a window of six years to adapt. Tertiary education would have a lead-in time of a dozen years.

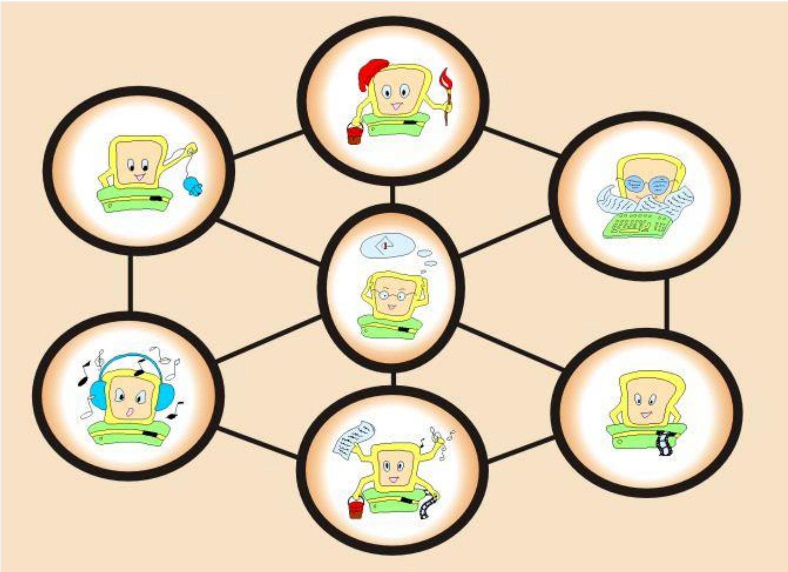

Figure 2. The “ToolKID” suite of programs used to introduce all the possibilities of working with the computer through a project oriented approach to children in the five to seven year age range.

The problem is that this curriculum is not obligatory so only certain children in certain schools develop any real level of competence. Resources were very much the inhibitor a decade ago but now computer systems that are perfectly suitable for primary education being thrown away as users upgrade. Computer supply is not the problem: the problem is perceptual and conceptual.

Tradition and transition

In the minds of both academics and educational administrators, including some constructionists, the traditional medium and methods with which they succeeded are perceived to be superior to the computer: they clearly exercise the little grey cells. Socrates had similar objections to writing.

A new medium inevitably causes concern, particularly where it affects high status skills. Hence in literacy and numeracy traditional method has been prescribed and the computer proscribed. In this climate, the transition to Turing teaching is inhibited and "ICT" integrated into the tradition.

A consequence of traditionalism is a disregard of work children produce using Turing media. An illustrated piece of writing is devalued as 'done on the computer,' a higher quality of thought and expression notwithstanding. This is illustrative of a factor that might be termed "academic blight" that currently infects computer application in education. The fragmented, subject led organisation of academe leads to a partisan approach to school: their must be in the curriculum. Furber (2012) is exemplary: A shortage of applicants for computer science motivated an inquiry into computing in schools by the Royal Society. Primary education merited only a half page of consideration, and then focussed on the final year; yet Furber, arrogantly and ignorantly asserted:

> *"We aspire to an outcome where every primary school pupil has the opportunity to explore the creative side of Computing through activities such as writing computer programs (using a pupil-friendly programming environment such as Scratch)."*

The derogatory words require justification. The problem is the conflation of writing and Scratch. Scratch uses words on labels that are grammatically colour-coded. The technique is identical to that used in certain remedial reading approaches; used when there is a learning difficulty. Scratch serves precisely this role (Wilenski 2010, Harvey & Mönig 2010). Primary school children learn to write by constructing words from letters and sentences from words. Programming is a way of writing a story. The teaching method should not differ. Scratch (LEGO WeDo software is worse) teaching method introduces splinter-skill learning, abhorrent to primary education. Here lies the ignorance; the arrogance is in gratuitously recommending an inappropriate teaching method to expert professionals. From a Turing teaching perspective, University is part of the problem.

Risk and technological transitions are always associated. The transition from atmospheric to high pressure steam power is an obvious historical example. Development of railways accelerated only when economic conditions were conducive. More importantly, the engineers and entrepreneurs who drove the development had little association with traditional horse powered transport. Rail viability was tested in parallel with road and canal, not in association. This may offer a model for transition from text to Turing media in education. It is also clear that change can only begin in primary school; attempts at secondary level can lead only to the teaching of splinter skills and to assimilation to traditional conceptual frameworks; or to disappearance without trace.

Teacher R&D capability, a way forward?

Expertise in the developing child's mind, at a level necessary for the effective implementation of innovation, is to be found only within the primary school teaching profession. To this must be added mastery of the medium. This suggests an engineering R&D based approach: a continuous cycle of pilot, assessment and scaling up. The cyclic aspect of the change process contraindicates the traditional academic project model, which has not been notably successful. A way forward is an R&D class in school, publicly or privately funded but independent of both the educational and political establishment, where a Turing teacher can develop method interactively with children. A source of technical assistance and software development would be required. It would help were such classes to operate on a regional basis, cf. EU Comenius programme, so that teachers and children could interact with colleagues. This is similar to the R&D model used for ToolKID.

Conclusion or?

The technicity proposition offers a solid base for constructionist change in education. Necessarily this starts in the minds of primary school children. The modes-of-learning analysis shows Turing teaching to be assistive and tuneable to emerging minds. Traditional method is obstructive and abusive, leading to an inadequately tamed language instinct. This reduces capacity for scientific relative to perceptuo-linguistic thought. The transition to Turing media is inevitable but fractured academe is seen to lack the necessary catalytic knowledge. Expertise resides, unarticulated, in the minds of primary school teachers who have mastered the medium. The implication is that R&D is best carried out in classrooms by practising teachers rather than through professorial projects. The original idea of Eurologo was to bring teachers and academics together as equals. It has failed to.

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Interactive Board Games in classroom

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Abstract

Interactive board games (IB games) are in fact board games that are played on the computer. Like traditional board games, they are played face – to – face by several human players (1-2 or more) who compete with each other following certain rules. We claim that when implemented as software products, these games can offer a richer experience to their players since they become interactive and parametrizable, features that are missing when they are implemented on a simple piece of carton. Interactive board games have one more advantage compared to other computer games: programming is necessary not only for creating such a game but also for playing it. This is the reason why we suggest a LOGO based programming environment as mostly suitable both for creating and playing IB games. In this paper we present the basic theoretical framework behind IB games, then we give an educational scenario for designing, creating and playing such games in classroom, and finally we give some examples of IB games implemented by students of the 6th Grade of primary school.

Keywords

board games, logo, programming, informatics curriculum

Introduction

For many years children and adults used to have a lot of fun by playing board games on a simple piece of carton. Nowadays computer games have dominated their free time, so that board games have been rather put aside. Computer and video games are much more attractive since they are colourful, parameterizable, offer action and interactivity. However it seems that board games are still important for many people, since they enhance strategic skills, rule based gaming and face – to – face interaction between the players [Kafai Y. 2001; Retalis S. 2008;]. Moreover the randomness, on which many of them are based, is an undisputable fun factor. Therefore trying to design and implement board games that can be played on the computer by one or more players can lead to a next generation of board games, which we call interactive board games (IB games). We chose this name since we believe that the main feature that is added to their rather static nature by transferring them on the computer is interactivity.

Interactive board games and computer games: a comparison

We will try to give a simple definition of a board game by quoting Wikipedia’s relative article found in http://en.wikipedia.org/wiki/Board_game:

[A ***board game*** *is a game that involves counters or pieces moved or placed on a pre-marked surface or "board", according to a set of rules. Games can be based on pure strategy, chance (e.g. rolling dice) or a mixture of the two, and usually have a goal which a player aims to achieve. Early board games represented a battle between two armies, and most current board games are still based on defeating opposing players in terms of counters, winning position or accrual of points (often expressed as in-game currency).*

There are many different types and styles of board games. Their representation of real-life situations can range from having no inherent theme, as with checkers, to having a specific theme and narrative, as with Cluedo. Rules can range from the very simple, as in tic-tac-toe, to those describing a game universe in great detail, as in Dungeons & Dragons (although most of the latter are role-playing games where the board is secondary to the game, helping to visualize the game scenario).]

The definition of a computer or video game comes also from Wikipedia found in http://en.wikipedia.org/wiki/Computer_game:

*[A **video game, computer game or console game** is an electronic game that involves human interaction with a user interface to generate visual feedback on a video device.]*

Here we should notice the fact that the IB games that we present in this paper should be also considered as computer games, since they are played on the computer. However they do not fall into the usual computer game categories: action, adventure, role-playing, simulation and their combinations [Zagal et al. 2006]. We would rather say that they form a new category of computer games. However for simplicity reasons, we will keep on using the term **computer game** to refer to the usual video, computer, console and electronic games, whereas we will keep the term **interactive board games (IB games)** to refer to board games implemented on a computer, although the distinction sometimes can be vague.

Computer games are often complex software products and their underlying mechanisms are frequently opaque to the average player. In contrast, board games are simple. Their game play is fairly constrained and their core mechanisms are transparent enough to understand. Besides most computer games are individual, while board games are multiplayer by nature and require face to face communication.

Another difference between IB games and computer games is who creates the action. In an IB game, the action of the game is created by the human players of the game supported by the chance and of course the rules of the game, whereas in a computer game the action is mainly created by the computer and the humans (one or more) just respond to this action or series of events. This leads us to think that IB games help their players to take the initiative over the machine and develop less pathetic behaviors towards the computer.

Last but not least, computer games are difficult to implement; they need a lot of effort, time and programming experience of a superior level. Often the results are not rewarding for young children and novice programmers since the games that they create are simplistic and not satisfactory enough for playing. Especially children that have the experience of professionally designed and implemented games can be easily disappointed by the result of their efforts. Any game should be: enjoyable, different each time and should have a satisfying result.

These are the reasons why we believe that board games worth being re-invented and continue to be played by children and adults.

Building IB Games in classroom: collaborative activities based on the constructionism learning theory

The advantages of using board games in education are well documented in literature: "*A board game is played by multiple players who move pieces across a premarked surface using counters or dice. Adding board games to the educational process can lead to an interactive learning experience*" (Helliar et al., 2000).

As it is obvious, the idea of transforming a traditional board game to an electronic one is not a new one (Retalis S., 2008). What bears some originality here is that we suggest that this has to be done by children or novice programmers in an educational activity framework.

The idea of games created by the children for educational purposes is a rather popular and well known constructionist idea. Y. Kafai in her article "Playing and Making Games for Learning" mentions (Kafai Y., 2006): *"The instructionists, accustomed to thinking in terms of making instructional educational materials, turn naturally to the concept of designing instructional games. Far fewer people have sought to turn the tables: by making games for learning instead of playing games for learning. Rather than embedding "lessons" directly in games, constructionists have focused their efforts on providing students with greater opportunities to construct their own games—and to construct new relationships with knowledge in the process".*

Therefore, designing and building of IB games is clearly a constructionist approach fully influenced by the constructionism learning theory (Kafai Y. et al., 1996). To think of Seymour Papert's popular saying: "Constructionism shares constructivism's connotation of learning as "building knowledge structures", irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity".

Besides, the face to face way of playing, makes a board game suitable for collaborative classroom activity (Zagal J, 2006, . Groups of students can collaborate not only at the design and building phase of the games but also while playing them. In classroom collaboration and interaction can really be leveraged by activities based on IB games.

IB Game making in the Informatics curriculum

At the initial stages of teaching programming, one has to find meaningful activities that are easy to be implemented by the learners in short time. We claim that the development of simple interactive board games fall into this category of activities. We also claim that a logo based programming environment is mostly suitable for creating such games. The LOGO language as it is well known possesses the inherent feature of drawing lines as traces left by the turtle objects (Papert S., 1993). Therefore it is rather easy to use such an environment for programmatically creating the board of the game, instead of doing so by using a common drawing tool. Such a practice has the following advantage: the board of the game may be changeable rather than being static. A changeable board may produce various gaming situations each time the game is played, or if their players want to do so. And it is not only the board but also the "dice" - or in more general terms the element that controls the randomness factor – that can be also created programmatically.

While making a game, a learner has to take a number of design decisions while he/she starts developing technological fluency. Just as fluency in language means much more than knowing facts about the language, technological fluency involves not only knowing how to use new technological tools but also knowing how to make things of significance with those tools and most important, develop new ways of thinking based on use of those tools. Beyond that, game-making activities offer an entry point for young gamers into the digital culture not just as consumers but also as producers (Kafai Y., 2001).

Due to the interpreted nature of the LOGO language (Papert S.: 1980) the programming environment can be used not only for programmatically creating the game, but also for playing it by using programing instructions of the LOGO language. The movement of each piece on the board can be in fact realized as the movement of a turtle on the LOGO canvas. Of course a turtle can move only when it receives the right instructions. That is something that helps learners to get familiar with the basic repertoire of instructions of the programming language and use the instructions to do something useful and meaningful i.e. to play the game. Moreover, in a simpler educational scenario intended for early childhood children, kids could just play a game created by someone more experienced in programming for instance their teacher or older children, by just giving the right programming instructions to the turtles on the electronic board.

The IB game educational scenario

As we mentioned earlier what interests us from the educational point of view is how to build and/or play IB games in classroom. In this paragraph we present an exemplar educational scenario (Beetham, H., 2007) that summarizes how this can be done. We chose to write the scenario in the form of a learner's activity worksheet, so that it can be easily understood and used by other teachers. This scenario is mainly meant to address groups of children between 11-13 years old, but it can also be used with groups of novice programmers or teachers with limited programming experience. The goal of the scenario is to guide the learners to create their own game, thinking first about design issues such as the rules, the narrative, the subject, etc. and then try to program their game. The scenario is divided in 3 stages. Each stage follows certain steps.

1st stage: designing the game

1. Think of a board game category. Board games fall into plenty of categories: they can be path games that are purely based on luck and chance like Chutes and Ladders or they can be based on strategy like Tic-Tac-Toe.
2. Whatever the category, it's better to find a theme. The theme can be related to a fairy tale, a book, some everyday life situation, etc. Pirates, kings and castles, space and horror, usually inspire children, although for adults, the scenarios can be different.
3. Map out the rules and the directions of the game. Some questions that a game designer must pose to himself/herself are the following:
   - What is the end goal of the game?
   - How would the players win?
   - What is the minimum and maximum number of players that can play?
   - What each player has to do every time it's his/her turn to play?
   - What are the pieces needed for the game? (Players' markers, dice, cards, etc.)
4. Sketch a rough draft of your board design on a piece of paper. This will allow you to determine whether you need to include more or less details in your final design. For path games, one needs to add start and finishing places, and set out a clear path or road for the character(s) to travel along.

2nd stage: implementation

5. You can choose to create your own designs for the images and pictures that will go on your game, but if you would rather use ready-made images, there are many resources on the Internet that you can do a search on and download to the theme selected in step 2.
6. Import any graphical images found and chose in step 5
7. Start to build the game programmatically. Create one procedure that builds the board of the game (that may call of course several sub-procedures).

8. Think of how you will treat randomness if the game is based on luck, i.e. what will serve as your dice and how the dice can be programmatically implemented.
9. Write one procedure that does game initialization (placing board, players and dice at original positions).

3rd stage: testing and playing

10. Test and retest your game plenty of times, by playing alone or with some peers. By testing it you can correct any unforeseen bugs or pitfalls. Ensure that the game rules are fair and that the game concept is fun and exciting for the target audience.
11. Ask from another group of peers to play your game, and try to play theirs. Discuss your experience and try to make some comments to help them improve their game. Make improvements to your game according to their comments.
12. Try to write a small manual of instructions, to help other people to play your game.

The above educational scenario is basically proposed for teaching initial algorithmic concepts and basic programming skills to children and novice programmers as said earlier, so it can be part of an informatics teaching curriculum.

The advantages that occur from the implementation of such a scenario in classroom can be summarized as follows:

- Children develop creativity and imagination since they are urged to think of the category and the theme of the game, the design of their characters the role playing scenario that defines the action that takes place while playing the game. Aesthetic criteria decision making and self-esteem are strongly enhanced at this stage.
- They have to come up with rules and directions: who wins, what a player should do when he/she takes turn. Implementing rules helps children develop logical thinking and strategic skills.
- While implementing the game by programming, they also develop basic programming skills and learn to program the computer by doing something that is meaningful.
- The last step of the scenario supports good-fellowship and camaraderie between children. Interactive board games like common board games need usually at least two players that play face-to-face. Interaction takes place between humans without the mediation of the machine.

In the next paragraph we will give some examples of IB games that were implemented in classroom by students of the 6th grade of the 10th public primary school of Maroussi in the Athens area during school year 2010-2011. The children worked in groups under the supervision of the ICT teacher for a period of two months (about 16 teaching hours) following the proposed educational scenario.

Examples

Example 1: the coloured dots game

The examples of the IB games presented in this section have been implemented with EasyLogo. EasyLogo is a LOGO based programming environment for young children or adults that want to acquire basic programming skills. (Salanci L., 2010). Easy Logo is a user friendly and easy to use programming environment with a very limited set of commands (~10). However due, to its simplicity, we consider it as the right programming environment for young children. The only serious deficiency that we noticed during the implementations of the games was the fact that there is only one turtle object on each canvas.

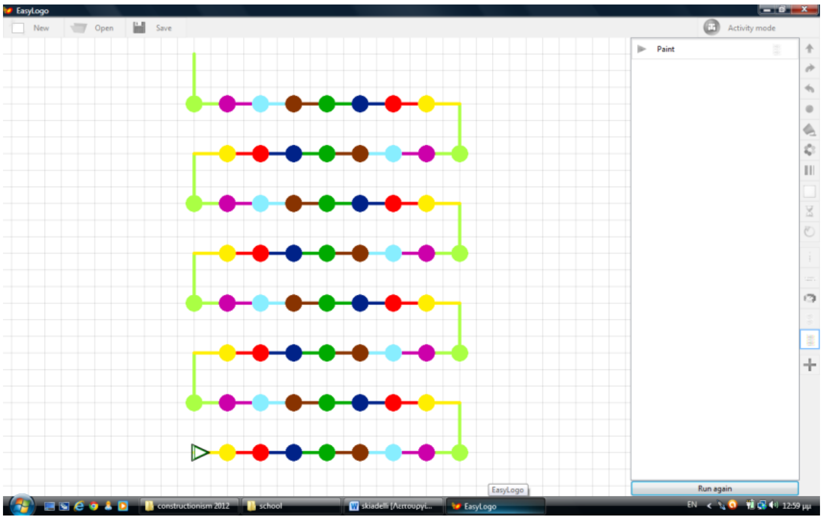

Figure 1. The coloured dots IB game

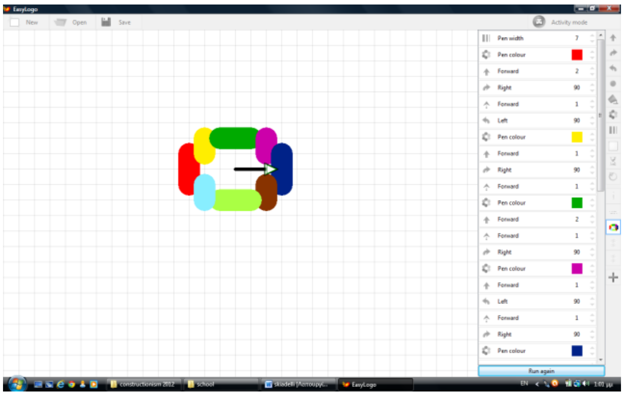

Figure 2. The implementation of the dice

The rules of this game are the following: players play in turns. Each player needs to roll the dice each time that comes his/her turn. To roll the dice the player presses the “Run Again” button and the arrow moves to a random colour of the circle. Then he/she gives the right logo commands in order to move the black arrow that appears on the board (i.e. the turtle) to the first dot that has the colour indicated by the arrow of the dice. The player that first reaches the last dot wins.

This game is a game based on luck that needs two or more players. It’s a very simple game that can be played even by very young children to help them practice basic LOGO language commands, orientation and numbering skills.

Part of the instructions given by the players for playing the game appears below:

paint[1] *3*
forward 6

[1] The command “Paint” in EasyLogo, in fact means “Run the procedure”. The number argument that follows this command is the code number of the procedure as assigned by the system each time. So “Paint 3” means “Run the procedure No 3” which is the procedure that draws the canvas of the game and does the initialization.

forward 4
forward 6
left 90
forward 3
left 90
forward 8

The game is implemented by four procedures: two for creating the board, one for creating the dice and one for the initialization that calls the other three. The first command given by the first player in the programming pane calls the fourth procedure. Below that call, each player places the programming instructions that move the arrow – turtle on the game board. The players have to change between the dice and the playing space canvas.

There can be a lot of alternative implementations both of the board and of the dice of this game. Another kind of board and dice that could be used for this game, are shown below:

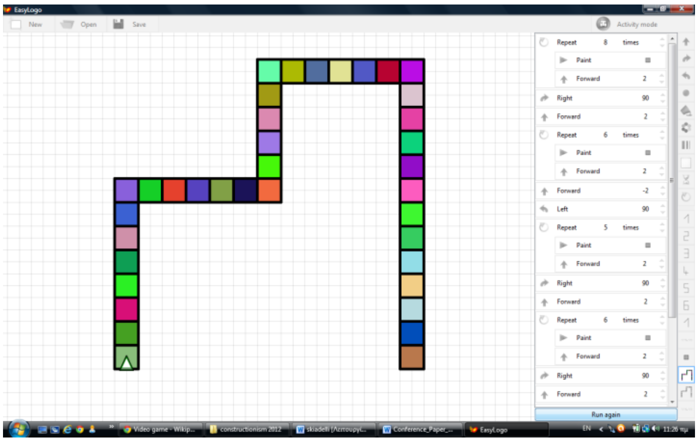

Figure 3. The coloured squares game (2)

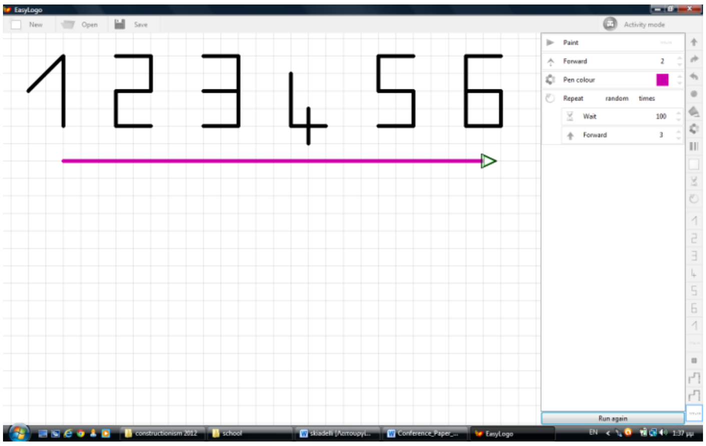

Figure 4. The implementation of the dice (2)

Example 2: the tic-tac-toe game

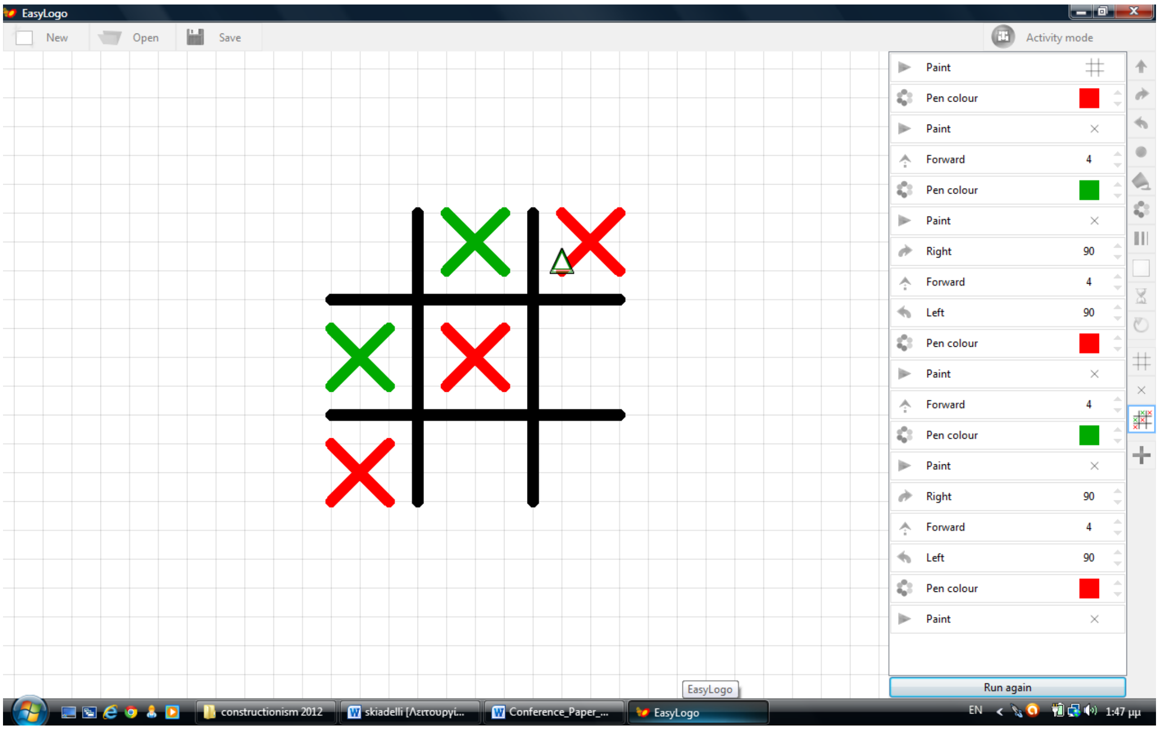

Figure 5. The tic-tac-toe game

This is the very common tic-tac-toe game that is played in the normal way by two players by giving programming instructions to place their X's on the cross board. The game is built by two procedures, one that builds the board, and the second that builds the **X** symbol. Each player has to put the X to the right place of the board by first moving to the right position and then make a procedure call to the **X** symbol procedure. Before that he/she has to change the colour of the pen to one that corresponds to his/her colour. A part of the code written by the two players while playing follows:

paint 0

pen colour = red

paint 1

forward 4 with pen up

pen colour = green

paint 1

right 90

forward 4 with pen up

left 90

pen colour = red

paint 1

forward 4 with pen up

pen colour = green

paint 1

right 90

forward 4 with pen up
left 90
pen colour = red
paint 1

Alternatively, the players can use the X symbol procedure and the dot drawing command, instead of the two different coloured X symbols.

Example 3: the maze

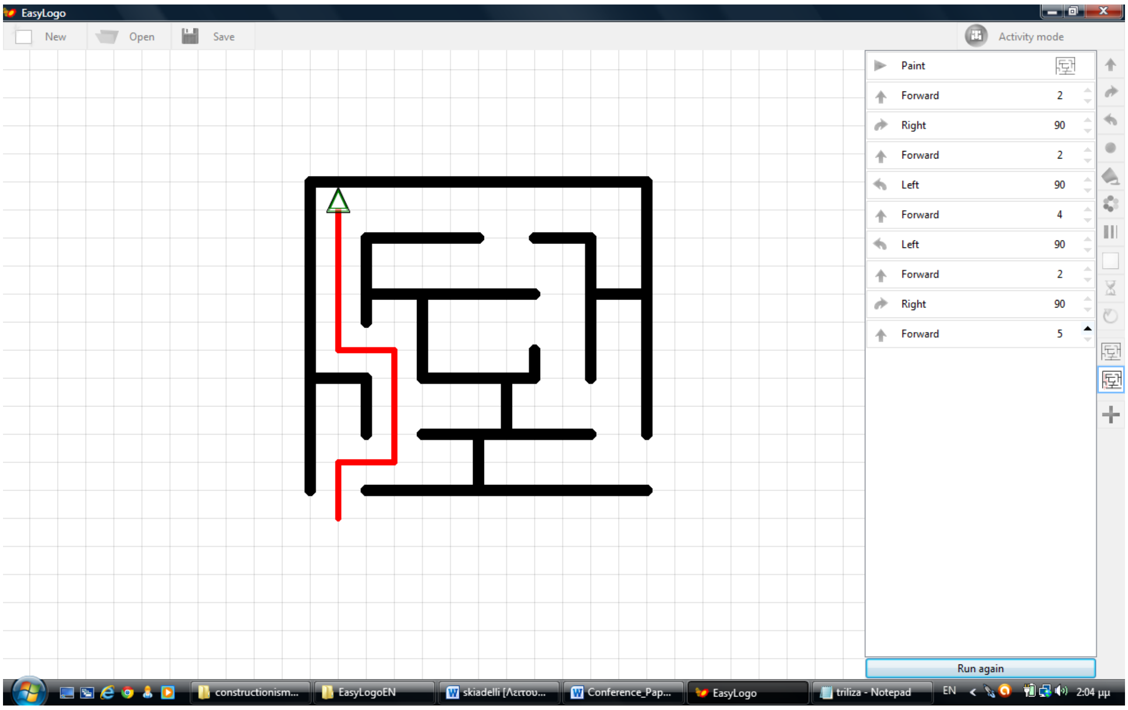

Figure 6. The maze game

The maze game is played by two players. One player builds the game and the other has to get out of it. One can also put a time restriction to make the game more challenging. What makes this implementation interesting is that the maze is drawn programmatically and therefore each time can be drawn in a different way. Again the player that has to get out of the maze needs to do so by giving programming instructions.

Conclusions and future ideas

The IB game scenario offer an educational framework for children (11-13 years old) and novice programmers to create simple but still meaningful software products that can share with their peers. Due to some of the inherent features of the LOGO language, these games can not only be created programmatically but also be played programmatically even by very young children between 6 and 9 years old. There is a lot of creativity that comes up with such kind of educational activities: children have to think of the category and the theme of the game, come up with rules and directions that have to be followed, develop strategic skills or other techniques to master the game. In the future it would be nice to explore the possibility to play such games on a touch screen environment like tablet pc or smart phone, interactive table board (MS) or even a touch floor. The idea of how the LOGO based environments can profit from touch based or movement based interface technologies has not yet adequately explored. This would give new perspectives to these environments and therefore to the interactive board games that can be built with them.

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Building the System of Designing Own Mathematics Textbook

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Abstract

Students in South Korea receive standardized education as learning contents and order of contents in mathematics textbooks follow the national curriculum. In order to find the learning order or methods best suited to learners, therefore, it is necessary to analyze the contents in the textbooks by elements and reconstruct them. From a constructionism perspective, this research will first analyze mathematics textbooks in South Korea to build an environment where teachers or students can design their own textbook by dividing the contents into pieces, and then look into the principles of web-based system design.

Keywords

Constructionism, Mathematics Education, Learning Object, National Curriculum

Introduction

Pointing out the problem of traditional mathematics textbooks which deliver contents in a given order, Freudenthal (1973) emphasized the need to reconstruct textbooks so that it enables students to experience 'guided reinvention'. Recent studies which stress the historic-genetic approach confirmed order of contents in the traditional textbooks may not always be appropriate to all students. Some teachers may prefer exploration-based learning while the others may prefer historic-genetic learning. However, one standardized textbook cannot support such different classes; therefore, teachers should be able to reconstruct the textbook on their own according to the learning objectives and the way to deliver the contents.

However, reconstructing mathematics textbooks in reality is quite challenging in some countries. For example, South Korea has a national curriculum and the national institution named Ministry of Education, Science and Technology (MEST) proclaims the standardized national curriculum. Like other subjects, mathematics textbooks are designed in accordance with the national curriculum which has been revised approximately every five year. All of elementary school students in South Korea use one single textbook and learn mathematics from the same contents in the same order. In middle schools and high schools, teachers choose one of the several government authorized-textbooks and all of the students in one school learn mathematics from the same textbook chosen. Being able to make a choice may sound better, but order of contents is almost the same although learning materials can be a bit different because all textbooks follow the national curriculum. That is, any math teachers in South Korea teach students mathematics in the same teaching order.

We anticipate developing technology would enable such traditional textbooks to be more flexible. Especially, we expect to build an environment where teachers and students can experience designing their own mathematics textbook. In order to reconstruct Korea's mathematics textbooks, the objective of this research is to look into the designing principles of the environment where teachers or students can analyze contents of textbooks by elements, draw units, and redesign their own textbook by putting the units together.

Theoretical Perspective

Ackermann (2004) argued that in comparison of Papert's constructionism and Piaget's constructivism, although both theories are of the same view, the roles of the media are more emphasized in constructionism. Here, the media being emphasized is a physical construction environment for mental construction. Likewise, Kafai and Resnick (1996) said that the core of constructionism is the mental construction through physical construction.

> Constructionism is both a theory of learning and a strategy for education. It builds on the "constructivist" theories of Jean Piaget, asserting that knowledge is not simply transmitted from teacher to student, but actively constructed by mind of the learner. Children don't get ideas; they make ideas. Moreover, constructionism suggests that learners are particularly likely to make new ideas when they are actively engaged in making some type of external artifact-be it a robot, a poem, a sand castle, or a computer program-which they can reflect upon and share with others. Thus, constructionism involves two inter-wined types of construction: the construction of knowledge in the context of building personally meaningful artifacts (Kafai and Resnick, 1996).

The computer environment to implement constructionism must be the one where learners can construct the artifacts they want and construct knowledge through the very construction activity. In other words, through this learning by making, learners naturally come to know of powerful ideas through the activity of physical construction.

Is internet an appropriate space for constructionism? Resnick (1996) used the term, 'distributed constructionism' as discussing how technology like internet can contribute to constructionism. He explained internet can help construction activities in the following three ways.

- Discussing constructions
- Sharing constructions
- Collaborating constructions

Internet here is a tool to discuss and collaborate construction, rather than a tool for construction. In fact, the internet web in the early stage was the media that deliver information existing in a virtual space to users. Therefore, researches on web-based learning generally aimed at resolving spatial or physical limitations through technology, and delivering the existing knowledge in a more effective way. Recently, however, web has been developed to an environment that can realize user-generated contents with interactive technology advancement. Web-based learning researches have expanded from studies on virtual space design that simply promotes knowledge delivery to studies on an environment which allows individually and socially meaningful physical construction. In other words, web has been developed from an instructionism tool for knowledge delivery to a constructionism tool for knowledge construction.

Going even further than just constructing a virtual object, web can be used as a space where people make their own hamburger or book (http://pediapress.com) that they can actually get hold of. Hamburger 2.0 (http://www.4food.com/) is an environment where people make their own unique hamburger by choosing a type of bread and other ingredients prepared and recombining them in the order that they like.

Churchill (2007) defined 'learning object' as a thing designed, as considering reusability, to be used in a different form of learning, utilizing various media. Learning objects are sort of learning resources and they may provide learners with a variety of customized education environments which help learners achieve the learning objectives depending on the way to combine the resources. Here, we would like to emphasize on reusability of learning unit elements.

From a constructionism perspective, we would like to design an environment where mathematics textbooks can be reconstructed. This environment is a web space which enables teachers or learners to reconstruct mathematics textbooks by adjusting order of learning objects and show learning contents provided by the national curriculum as a combination of various learning objects.

Analysis of Korean Mathematics Textbooks

According to South Korea's national curriculum revised in 2009, all students up to 3rd grade of middle school are supposed to complete the same curriculum (MEST, 2009). One distinctive feature in 2009 revision is that it did not rule order of learning while setting the required learning contents. The mathematics curriculum was revised in 2011 based on this principle and Table 1 shows the number of learning contents given in respective grade's curriculum (MEST, 2011). That is, studying the learning contents shown in Table 1 is mandatory to all elementary and middle school students.

Elementary 1st ~ 2nd grade	Elementary 3rd ~ 4th grade	Elementary 5th ~ 6th grade	Middle 1st ~ 3rd grade
14	24	20	29

Table 1. The number of achievement standards in Required Courses

High school students are supposed to complete a few subjects chosen from 6 electives, depending on their future career plan. Even if these are electives, the learning contents in each elective are decided by the government. Table 2 shows the number of learning contents in each elective.

Mathematics I	Mathematics II	Calculus I	Calculus II	Probability and Statistics	Geometry and Vectors
12	9	10	8	8	8

Table 2. The number of achievement standards in Electives

Newly developed mathematics textbooks have similar order of learning because the contents are similar to the ones covered in the pre-revision textbooks.

We would like to design an environment where we can reconstruct mathematics textbooks by rearranging order of contents while not getting out of the learning contents given in the national curriculum. However, this does not mean simply changing order of contents. A learning content is comprised of several learning objects and we need to make all learning objects' order changeable as an independent unit. For learning materials, in addition, we would provide various learning objects that allow construction of various learning contents with one learning objective in order for learners to design unconstrained learning path. And we would unify the form of learning objects given in learning contents. Having a variety of learning objects is to allow teachers or students to make various combinations and unifying learning objects' form is not to be bound by grade when creating mathematics textbooks.

The form commonly presented in several textbooks can become an appropriate form of learning objects. For this, we analyzed textbooks used in elementary schools and in the 1st, 2nd and 3rd grade of middle schools. Table 3 shows the number of textbooks analyzed. We particularly focused on analyzing the middle school textbooks and this is because the design conducted in this research plans to be built in 2012 and applied to middle school students on a trial basis.

Elementary School	Middle School – 1st grade	Middle School – 2nd grade	Middle School – 3rd grade
1	27	17	14

Table 3. The number of mathematics textbooks

Designing the System

As a result of textbook analysis, we were able to find out many learning contents generally have the same learning order. In addition, we concluded a learning content has the following 7 types of learning objects in common although it slightly varies depending on the textbooks. Also we learned order of learning objects are presented in an identical order in most of the textbooks. The followings are the 7 types of learning objects that we discovered.

- Conceptual learning: This is about concepts and explaining the concepts. The concept explained here can be more than one. It does go beyond what traditional mathematics textbooks covered.
- Exercise problem: This is about problems to explain a certain concept or simple problems that apply the concept understood. Mathematics textbooks in South Korea include a variety of easy to difficult problems. Textbooks present the problems when one part of learning contents is completed or use the problems to explain a certain concept.
- History of mathematics: Many mathematics education researches stress using history of mathematics in the teaching (Freudenthal, 1983). History of mathematics can arouse students' interest or can be used as a tool to develop the contents according to the order of historical occurrence of mathematics. Such endeavours have been included in mathematics textbooks since 1990's. In most cases, this is limited to listing up historical facts on mathematics in text; however, this can be presented in a dynamic form such as a video clip or animation if we can use a web-based virtual space.

- Exploration: Mathematics also requires exploration as other subjects in natural science do. A strategy like 'What if not' is a very important strategy in mathematical thinking and problem solving. For this, it is necessary to have mathematics laboratory where students can explore and experiment their conjecture. Even if current mathematics textbooks cover it in the form of 'Learn More about It', paper textbooks reach the limit to expressing dynamic mathematical experiments. However a web-based space can make dynamic mathematical experiments possible. In this context, introducing Microworld and mathematical experiment using the environment are meaningful. Edwards (1995) defined the microworld as follows and explained about exploratory learning, using microworld.
    - A microworld contains a set of computational objects.
    - A microworld links more than one representation of the underlying mathematical or scientific entities or objects.
    - Often the objects and operations in a microworld can be combined to for more complex objects or operation.
    - Typically, a microworld includes a set of activities (Edwards, 1995).

  It is desirable to provide Logo (Abelson and diSessa, 1980; Papert, 1980), Geogebra (http://www.geogebra.org), JavaMAL (Cho et al., 2010) in learning object and it is also feasible in reality.
- Mathematical communication: The mathematics curriculum revised in 2009 (MEST, 2011) emphasizes on mathematical communication in addition to mathematical reasoning and mathematical problem solving. With the stream, recent textbooks include open-ended mathematics questions that encourage students to discuss to answer. If these contents are linked to Social Networking Service (SNS) technology, mathematical communication in online spaces would become available. Then, we may expect active communication environments where students and teachers ask questions and answer thru SNS like Facebook or Twitter. This can be a good way to actualize distributed constructionism that Resnick (1996) mentioned.
- Problem solving: Many countries have emphasized on problem solving ever since Pólya (1957) addressed one of the most important objectives in mathematics education is problem solving. Besides NCTM (2000), problem solving is one of the critical objectives in South Korea's mathematics curriculum. Most of the mathematics textbooks in South Korea include problem solving parts separately in the middle or end of chapters. The problems presented in this learning object are different from the exercise problems presented to help students understand a certain concept. They are rather related to a real life or include mathematics problems and experiments with solutions which require many stages of thought process.
- Cartoon: Mathematics textbooks that can be somewhat dry may also include interesting contents. In a web space, these contents can be provided in the form of webtoon or animation unlike cartoons in a paper textbook. If contents are constructed with well-structured characters in the whole context and frame, this may stimulate learners' interest and achieve educative results to some degree.

The 7 types of learning objects reviewed above may have various representations and they can be represented in the form of text, video or even manipulable laboratory.

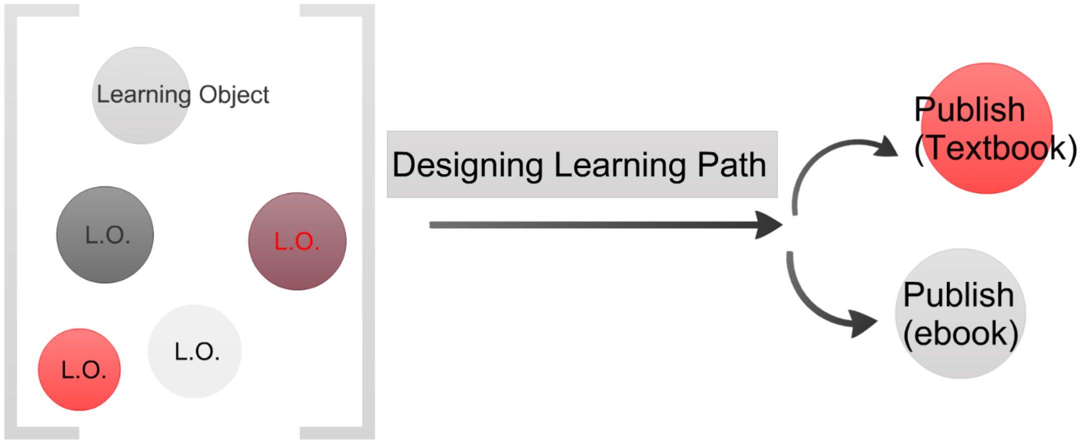

Figure 1. Designing own mathematics textbook

A Prototype of the System

Figure 1 is the image of the system that we design. The learning objects in Figure 1 are from the 7 types of learning objects reviewed above. Users may publish their own book by combining different learning objects and this textbook can end up with a paper book or an e-book with dynamic presentation. Some may only insert video-clips in their own textbook while leaving table of contents as it is. Others may create a paper comic book or an e-comic book by adding different cartoons. Students and teachers would learn by creating a physical construction - their own mathematics textbook, and learn mathematics by using such physical constructions.

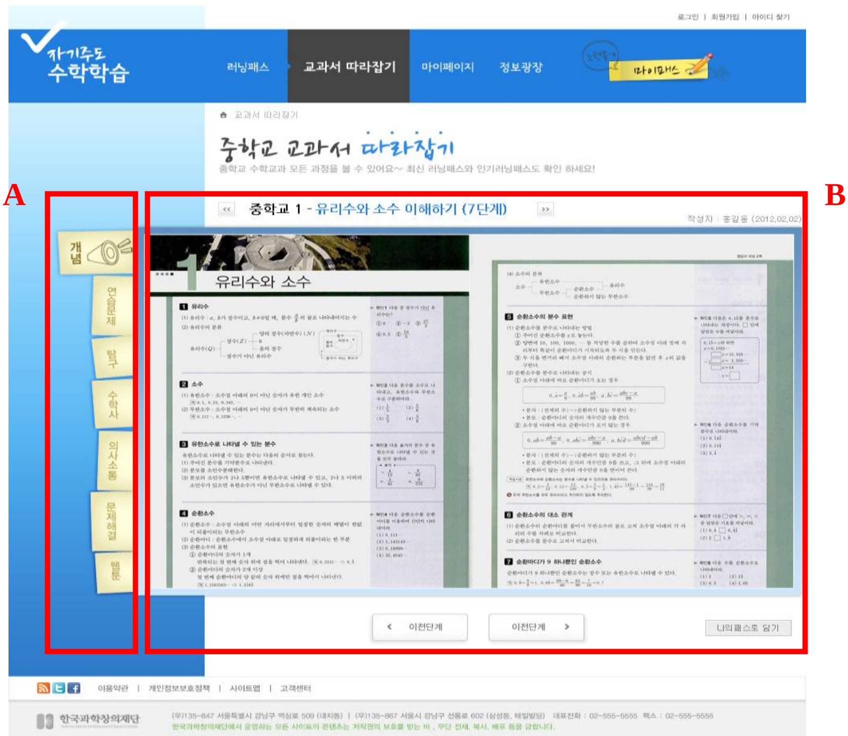

Figure 2. Prototype of mathematics learning website

Figure 2 is the image of the system represented in a web space we designed. Part A shows the learning objects included in learning contents and Part B shows the items in learning object. Figure 2 shows 'Conceptual learning' learning object in the 'Rational Number and Prime Number' learning content. By clicking the learning objects in sequence presented in Part A, users may study the contents as intended by the content designer. Or they may study the contents on their own way by clicking the learning objects that they are interested. In addition, users can refer to the curriculum that covers the learning object that they are studying regardless of which one it is because all learning contents are included in South Korea's curriculum. This is very important as teachers and students in South Korea are very familiar with content organization and content order in textbooks due to the unique government control on the curriculum and textbooks.

Figure 3. Prototype of creating mathematics textbook

Figure 3 is a tool that enables teachers or students to create their own mathematics textbook. Users can choose learning contents in STEP 1. Teachers and students in South Korea are familiar with the way contents are organized in textbooks; therefore providing order of contents is convenient when they look for certain contents. They can certainly find the contents by searching keywords as well.

Learning objects are presented in STEP 2 once the contents that users would like to include are dragged from STEP 1. In STEP 2, users can pick and choose certain learning objects and put them in their My Path. Users can choose up to 7 learning objects and also select one learning material from respective learning objects as learning materials are pre-registered in each learning object. For example, there can be three cartoons related to negative number while there can be one cartoon related to fraction. Usable learning objects are added continuously. Teachers and students put all learning objects that they would like to include into My Path by coming back and forth between STEP 1 and STEP 2. In STEP 3, they complete to create their own mathematics textbook by adjusting order of learning contents in My Path and putting a title. The completed mathematics textbooks can be used by other students and teachers in online spaces or can be delivered to the users after the bookbinding process.

Closing Remark

This research examined South Korea's mathematics curriculum and textbooks. In South Korea, the government is responsible for curriculum research and development, and allows only government-authorized textbooks to be used in schools. As analyzing textbooks, we found out mathematics textbooks include learning contents in common in a given order, and each learning content is comprised of 7 types of learning objects. Based on this finding, we looked into the features of the web-based system and the prototype where the forms of constructionism-based mathematics textbook can be realized. Then, we built the system and the prototype where users can create their own mathematics textbook, using modulized learning objects selectively, given that the contents in mathematics textbooks have a certain forms (learning contents and learning objects).

This research will be followed by another study, not just limiting it to a theoretical study. The system we designed has a plan to be built in the second half of year 2012, targeting middle school students. Once the service begins, we will follow up with a study to see how teachers and students use the system in their real life. In particular, we will intensively look into how and in what forms the new type of textbooks used in a web space would be constructed.

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Back to the Future: Can we reverse a quarter-century of regression?

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Abstract
25 years on! Thoughts on the future constructed from a mistily remembered past. The cause of present predicaments is analysed from the perspective of a traditionalist ascendency. Eurolog87 aspired to change teaching. In the spirit of '87, but now with resources, a call to arms is voiced.

Keywords
Logo, primary education, constructionism, traditionalism, teaching method, medium, reflection

Introduction

The first Constructionist conference, nee EuroLogo, took place in Dublin, Eire at the beginning of September in 1987. Thanks to the hiatus before Constructionism 2010, this biennial European conference now has a silver jubilee. A time for reflection on what might have been and the forces that derailed the hopes of the early 1980s. From the author's perspective, that of a teacher focussed on the primary phase of education, this period has been one of powerless frustration trapped between the rock of educational traditionalism and the hard place of the short-term projectism of a fragmented academe; not forgetting the commercial pressures from a hard-selling ICT industry. However it is the former that are most germane to this discussion, which will begin with 1987 and conclude with 2012.

The intervening years have seen much technological development. However, on the basis of two recent major reports in England: The Cambridge Primary review (Alexander 2010) and the Royal Society Inquiry into Computing in Schools (Furber 2012) it is possible to assert that in real educational terms there has been regression rather than progression. Many factors contributed to this, some of which arose from the Constructionist community (notably the conflation with educational philosophy). The major regressive influence, however, originated in the educational traditionalist reaction to so-called progressive education. Although the English experience of the traditionalist agenda will form the basis of the discussion, the zeitgeist means that the analysis has general application. This is seen in the terminology that has been inflicted on education: first IT (information technology) then, with the Internet, ICT (add communication) and now merely "technology," which must be new. Thus, pencil, paper and book are not in this sense technology, whilst the latest hardware, whether laptop, whiteboard or tablet, is. The notion that the computer in the classroom was a new medium with an entirely different relationship to the developing mind of the learner from the text media that were the stuff of schooling (Doyle 1986) was rapidly lost. In such an intellectual environment constructive thought is difficult. However, let us begin with Eurolog87 and compare then with now.

Eurolog87

The Dublin conference was conceived as a meeting place between educational academics and the practising teachers who must convert their ideas into practical classroom activities: lessons. The

Eurologo biennial conference tradition was established by an informal group meeting at the 1986 British Logo User Group conference in Birmingham in 1986. Its timing was designed to coincide with the school long summer holiday so that teachers, who seldom receive conference funding and never receive career points for attendance or presentations. The Birmingham conference was also notable for the first European presentation of LogoWriter by Brian Silverman and that year also saw the launch by LEGO of its Interface A and LEGO TC Logo, soon to be teamed with LogoWriter as LogoWriter Robotics.

Eurolog87, note the absent final 'o,' produced no proceedings. All that remains are a few individual notes and the odd programme. The cover of the latter is reproduced below, with a list of the presentations.

A. Martin	Adaptable Microworlds for the History Classroom
C. Morgan	Introducing Logo to Young Children
J. Arias	The Intergalactic Turtle
Twomey/O'Dowd	LogoWriter for Beginners: Workshop
Butler/Close	Logo and Mathematically Gifted Children
N. Flavin	Logo in Secondary Education
P. O'Sullivan	Logo and the Primary Curriculum
M. Costello	Logo for Beginners: Workshop
K. Johnson	The Brain-Damaged Programmer: Effects of Exposure to BASIC
J Staines	Turtles: Past, Present, and Future
C. Kranz	Teaching Deaf Children with Logo
R. Eyre	Control Logo Master Class
J. MacNemara	Logo in Irish Primary Education: The Pilot Project
M. Valke	Report on the Integration of Logo into the Mathematics Curriculum of the Primary School
M. Holland	Logo with Mildly Mentally Handicapped Children
T. Olsen	Simplified Logo for 4-6 Year-olds
B.Denis	Teacher's Profile in its Relation to the Attainment of Specific Objectives in a Logo Environment
N. Fernandes	Heuristic Learning with Logo
H. Leibling	3 Dimensional Logo Master Class
J. Hardy	Logo: Storms and Beacons
R. Penny	Logo and Design for Non-advanced Further Education Students
E. Murphy	The Use of Logo to Develop Meta-cognitive Mathematical Skills
H. Loethe	The Space Turtle and Spatial Imagination
J Mallatratt	The Lancashire Logo Development Project: an Attempt at Curricular Integration
M. Doyle	An Evolution of the Physical Turtle
A. Martin	Adventure Games Master Class
Jansen/Kock	Developing a Curriculum Informatics in a Modular Logo System
M. Sweeny	Cognitive Development: with and without Logo
G. Enright	Logo with Disadvantaged Children
Close/Butler	Children's Problem Solving Processes in Logo
C. Kranz	Logo in Second Level Education in Luxembourg
H. Pinxteren	LCN Logo

Figure 1. Eurolog87 programme cover and presentations

The themes are not dissimilar from those at Constructionism2010. However, a little historical perspective is needed to interpret the presentation titles. To begin with, the word "Logo" did not necessarily imply the use of the programming language. An unintended consequence of the focus on turtle graphics in *Mindstorms* was the conflation of "Turtle Talk" with Logo. This meant that a majority papers were actually on the theme of turtle graphic commands and the use of floor turtles to implement them. In cases where mathematics was included in the title, particularly at primary school level, Logo was synonymous with turtle graphics. Where control technology was involved, Logo also may not have been the programming language. Often a so-called Logo-like interface, one that copied Logo vocabulary and some punctuation without implementing list-processing, was used. In England, such software was written in BBC Basic, with which the machine was supplied as standard. The pictures below illustrate these two major strands of Logo:

Figure 2. Control technology (LEGO Interface A) and turtle graphics

on 8bit pre-mouse microcomputers.

The third strand, characterised by LogoWriter, was the text/literacy aspect. The adventure games were a popular text-based activity as was the proposed use in the history classroom. LogoWriter, however, structurally went further than this. Alone amongst Logo implementations, it emphasised the change in the medium. With the programmable word-processor commands children and teachers were provided with a powerful tool actively to explore text. Nowhere was the difference between a sheet of paper and a screen made more obvious. The procedures page was a delightful exemplar. Below is a segment of a program as it might appear on this page, which in other implementations is the editor. Note that the same type and layout is used as for body text. This is because it is the words that matter, not the chosen font or formatting.

The procedures on this page illustrate the "square/diamond" effect and make use of turtle graphic commands. First we need a square:

```
to asquare
if equal? :count 4 [stop]
forward 100 right 90
make "count sum :count 1
asquare
end
```

Note: because this draws a square by counting the number of times the segment side/turn is carried out, it is necessary to zero the counter before beginning. To do this, type: make "count 0 before drawing the square. This may be done automatically with a slight change in procedures, as follows:

```
to square
clean home
drawsquare 0
end
```

This is the calling procedure. It calls the procedure below with the counter set to zero.

```
to drawsquare :count
if equal? :count 4 [stop]
forward 100 right 90
```

```
drawsquare sum :count 1
end
```

The diamond procedure is now simple to write:

```
to diamond
clean home right 45
drawsquare 0
end
```

Alternating the square and the diamond is trivial:

```
to squarediamond
square wait 20 diamond wait 20
squarediamond
end
```

This makes a very clear statement about the intended audience for the text. Between a "to" and an "end" the audience is the computer. After "end" and before "to" a human audience is the target. For a child in primary school this makes far more sense than the computer scientist's semicolon comment convention. It encourages making of the link between natural and computer language and helps the child to explain what they are trying to do in (Vigotskian) internal language. It also fits the Logo, eat the elephant in small pieces, approach. And, with a little care over "intelligent" double-quotes, the text above may be copied directly into the editor (both LogoWriter and the current Microworlds) where the natures of procedure and narrative are clearly demonstrable.

Readers will have noted the emphasis placed on primary education. This is because it is what it says on the tin: primary education. This phase of education is the basis for all that follows; and if something is not included in the curriculum in these years, it will not be available for building upon in the secondary and tertiary phases.

The Interregnum

The paper "Storms and Beacons" had an apposite title. As it was being presented, the educational traditionalists were cooking up the first English National Curriculum for over a century. Imposed from 1988, is prescribed what should be taught in schools in the country. Thus, England stepped into line with most jurisdictions where educationalists implemented executive instructions. In these statutory documents Logo, officially, ceased to exist. Logo for the BBC Microcomputer had a single monopoly supplier and politico-commercial interests ensured that what might be deemed a brand name should not appear in government publications; notwithstanding the fact that there were multiple turtle graphics packages masquerading as Logo. This suggests that lack of official support for Logo was associated with a dislike of programming on behalf of the traditionalists.

Traditionalism ruled not only within the national curriculum but also in the executive's response to perceived poor standards of literacy and numeracy. In both these core aspects of the primary school curriculum the legislators prescribed traditional methods of teaching and proscribed the use of computer technology. The potential of the new medium to assist learners went explored in an agenda that relied on assessing traditional attainment achieved through traditional methods.

The current nostalgia about early computers in school masks some critically important factors. The old eight bit machines had small memories and lacked a mouse. There was only one in each classroom, if you were lucky. The cost of computing was high and the notion that a child might have their own was inconceivable. The advent of the mouse and windows had a significant effect on Logo. The first casualty was turtle graphics. Offered a mouse and a paint package, primary school teachers quickly abandoned turtle drawing, with which many had been uncomfortable. The death of LEGO-Logo was more lingering. It began with the RCX programmable brick in 1998. Some three years after the launch of Windows 95, the fashion for GUI interfaces led LEGO to abandon Logo and embrace a child-oriented graphic programming environment based on NI LabVIEW, a professional engineering environment. Although there remains Logo support for both the RCX and NXT, it is not supplied with the product and must be sought out. Thus, by the end of the twentieth century, Logo had lost its place in school – almost. Some suppliers embraced the new graphical world and produced new implementations. Microworlds and Comenius Logo, from LCSI and Comenius University in Bratislava, and MSW Logo, were notable. The Comenius implementation included graphics as first-class computer data. Animation was now on offer.

As computers became more ubiquitous, it began to become apparent that children needed to be taught to master the medium. Most jurisdictions had a curriculum framework that was difficult to modify. Bulgaria, however, had three levels: obligatory, obligatory elective, and elective. The last was a curriculum that was approved for use in schools but the teaching of which was optional. For this latter category a curriculum which would lead to mastery was written by Ilieva (Ilieva & Ivailov 1999) for all four years of primary school. Comenius Logo was used to write a collection of supportive small programs. Turtle graphics did not feature, but LEGOLogo did. Some progress has taken place as a similar curriculum, with the control technology removed for economic reasons, was elevated to the obligatory elective grade in the mid 2000s. Here it was one of a selection of options that must be chosen. However, as in other countries, the traditionalists hold sway and it is not likely that mastery of the computer as a medium will become obligatory. Although standards are set, as in England there is no quality control and children enter secondary education with widely differing competences. The curriculum and its software and method were reported to Eurologo conferences beginning with that in Sofia in 1999 and concluding with 2010. In this context, it is notable that the curriculum originated in a primary school and was developed by practising primary school teacher rather than a university researcher or academic.

During this period the notion of Logo as "a philosophy of education and a family of programming languages," the former derived from Piagetian concepts and the latter from Lisp and thereby the Lambda calculus, metamorphosed into constructionism (LCSI 1999). Focussed on making not talking, the core of the philosophy was the creation of a public object open to inspection (and thus dissection). This was not unconnected with the informal finding that in third world countries, it was practical people rather than educators who grasped Logo concepts most readily; echoing the situation with the traditionalists in England. Unfortunately, constructionism, like its forebear constructivism, lacked the science base that Piaget (1971) had longed for and for which Papert later expressed hope (Harrel & Papert 1991). Nonetheless a re-baptism was imposed: in 2008, EuroLogo became Constructionism. Teachers were notable by their absence from Paris in 2010.

Twenty five years on

Technology has developed considerably since 1987. Tape loading of software has given way to online download, CD and USB stick. Memory and displays are vastly improved. Where the BBC Micro had 32KB the modern computer has 2GB. CRT displays have given way to flat LCD high definition colour screens that react to touch. Teachers have multimedia projectors instead of chalk boards. Computers are no longer a scarce resource: perfectly serviceable Windows 95 machines hit the dump some years ago and are now being followed by their XP successors. The notion of personal ownership of a computer by a child, at home if not at school, has become the norm. But, to quote Richard Noss (2011), the influence of AI on education over the past twenty five years has been extremely small. Where do we really find the EuroLogo community situated now? Let us first consider the areas covered in 1987.

Turtle Talk, the mainstay of Mindstorms, is mere shadow on the classroom wall. MicroworldsEX has no turtle on its page unless you put one there. It does, quietly, retain the procedure page design of LogoWriter and all the text primitives have returned. There is support in the Robotics version for LEGO RCX and NXT but not for Control Lab for which LCSI wrote the software. Imagine does not have the same range of primitive facilities, though LogoWriter may be written with the inbuilt primitives and there is serial communication which could make the RCX and Control Lab operable from it; but its strength is in programmable graphics.

Children now arrive in school with excellent mouse point-and-click and browsing skills. But the failure of traditional education to address keyboarding seriously has led to children have limited skills in this area. The lack of the one and the presence of the other motivated a point-and-click, drag-and-drop approach, to which both the Logo and LEGO community succumbed.

WeDo from LEGO and Scratch from MIT nicely illustrate the effects of the last two and a half decades. Below is an illustrative WeDo model with LabVIEW-style and Scratch screens.

Figure 3. LEGO WeDo and its drag and drop programming environments

It is instructive to compare the WeDo projects with those for Interface A

LEGO Dacta Technic 9700	LEGO Education WeDo 9580	
three colour traffic light	spinning top	sitting-up lion
car with bump sensor	dancing birds	flapping bird
inclined plane start gate and timer	drumming monkey	goalkeeper and ball kicking mechanism
turtle-style buggy with line follower	hungry alligator	jumping soccer fans
fairground roundabout	rocking boat	giant that stands up when winched by a crane
supermarket conveyor with item detector	aeroplane which changes engine speed with tilt	
washing machine with door interlock and indicator lights		

Table 1. Comparison of LEGO WeDo and Technic school projects

The 1987 projects related very clearly to “robotics” that children met in everyday life and which they could discuss before, during and after construction. The Logo programming environment enabled them to turn their words into computer programs. The 2009 WeDo projects all came out of the toy box. The same is true of the software. NI LabVIEW has been turned into a kid-friendly toy version of itself. The ethos is like a little girl dressing up in mummy's clothes and pretending to be adult. Drag and drop Scratch is the better indicator of the real situation. Because children did not learn how to program in primary school, draggy dropping was seen as the solution to lack of capability. Unfortunately with the graphic interface came a degree of inelegance and the link to language was broken. The control blocks, typified by the loop, have all the intellectual content of a BASIC goto. Look at the two programs in figure X: do they relate in any way to the behaviour of the drumming monkey or are they just isolated motor instructions? How does a child know that this program is for the monkey? There are no links to the core curriculum of primary education. From the perspective of a professional primary school teacher tasked with providing a broadly based education whilst focussing on literacy and numeracy, Interface A and its projects attached to an aged Win95 computer running LogoWriter Robotics is the sounder educational option.

In an attempt to attract children to their subject, the engineers, with the toymakers, pandered to a consumerist entertainment obsessed marketplace where humanoid robots inhabit fantastic futures. The promise of 1987 had faded and the computerists all retreated to the technology ghetto where they were not challenged by, and could avoid challenge to, the traditionalists. Lost on the way was the spirit of '87 where robots were seen as disembodied devices designed to help people.

Traditionalist ascendency

The present situation is well summed up in the words of the two reports cited in the introduction. Alexander, a committed primary school traditionalist in the Vigotskian mould, led the team that produced the most comprehensive report on English primary education in a generation. His view on "ICT" encapsulates the present traditionalist position. The relevant section of the summary report is reproduced in full below:

> **Language, oracy and literacy**
>
> This domain includes spoken language, reading, writing, literature, wider aspects of language and communication, a modern foreign language, ICT and other non-print media. It is at the heart of the new curriculum, and needs to be re-thought. Literacy empowers children, excites their imaginations and widens their worlds. Oracy must have its proper place in the language curriculum. Spoken language is central to learning, culture and life, and is much more prominent in the curricula of many other countries.
>
> It no longer makes sense to pay attention to text but ignore txt. While ICT reaches across the whole curriculum, it needs a particular place in the language component. It is important to beware of the perils of unsavoury content and long hours spent staring at screens, but the more fundamental task is to help children develop the capacity to approach electronic media (including television and film) with the same degree of discrimination and critical awareness as for reading and writing. Therefore it demands as much rigour as the written and spoken word.
>
> The Review disagrees with the Rose report's decision to establish ICT as a separate core 'skill for learning and life,' especially in the light of some neuroscientists' concerns about the possible adverse effects of overexposure to screen technologies. Placing it in the language component enables schools to balance and explore relationships between new and established forms of communication, and to maintain the developmental and educational primacy of talk.
>
> Every school should have a policy for language across the curriculum. If language unlocks thought, then thought is enhanced and challenged when language in all its aspects is

> pursued with purpose and rigour in every educational context. Language should have a key place in all eight domains and children should learn about the uses of language in different disciplines.

The more technical aspects and uses of computers, he believed, would properly be included in the technology curriculum. With this viewpoint, the Royal Society Inquiry appears to concur. In his introduction, Furber wrote that:

> We aspire to an outcome where every primary school pupil has the opportunity to explore the creative side of Computing through activities such as writing computer programs (using a pupil-friendly programming environment such as Scratch)."

Both these statements, (other than the parenthetic reference to Scratch), could have been made in 1987. Papert had argued for programming by young children long before that and Logo had been developed for this purpose in 1967. That today it remains an "aspiration" tells the whole story.

The Alexander extract echoes in its focus and language the 1988 Kingman report on the teaching of the English language, from which the following extract is unashamedly reproduced:

> Round the city of Caxton, the electronic suburbs are rising. To the language of books is added the language of television and radio, the elliptical demotic of the telephone, the processed codes of the computer. As the shapes of literacy multiply, so our dependence on language increases. But if language motivates change, it is itself changed. To understand the principles on which that change takes place should be denied to no one.

Oracist that he is, Alexander omitted reference to the fourth aim of Kingman, the one that offered Logo an entrée, were it to elect to accept it:

> to teach pupils *about* language, so that they achieve a working knowledge of its structure and of the variety of ways in which meaning is made, so that they have a vocabulary for discussing it, so that they can use it with greater awareness, and because it is interesting.

This was interpreted by traditionalists as the requirement formally to teach grammar. The narrow focus of the Logo community on mathematics and computer science meant, fortunately given the resource issue, that the potential of Logo to contribute to this went largely unexplored. But this, understandable, myopic focus became demonstrably maladaptive in the intervening years

Whilst Furber, the originator of the successful ARM processor and designer of the iconic BBC Micro, now seeks to use school to attract more students to his university courses; Alexander, a one-time member of the educational "three wise men," is blind to technology and joins with our Neanderthal cousins in elevating speech to the level of thought. The depth intellectual failure exhibited by these reports from the English Establishment is breathtaking. It is as if Alan Turing had never raised the question of the relationship of the computer to the human mind.

Reviewing the situation

What might be rescued from the debris of the past quarter century and what would better be discarded? LEGO has provided a focus for much of this discussion and may now be employed as a metaphor for primary education. LEGO is a system. Sold in toyshops as isolated models, the bricks can be assembled into a multitude of constructions. Both Interface A and WeDo (and the intermediate Control Lab, RCX and NXT) were similarly sold as isolates and similarly may be combined with the elements of the system to build scenes. An example of this system approach was presented a Constructionism2010, from which the example below is reproduced.

Figure 4. LEGOLogo embedded in the LEGO system to teach thoughtful construction in primary school

By embedding the robotics elements in a scene built using the system, a more cohesive whole is produced, compared to the positioning of isolated models against a hastily scribbled background. Here, the full educational benefits of the construction system are realised.

Primary school is a system in which minds are made. It is possible to develop splinter skills in the manner of isolated models. Much more preferable is for all activities to contribute to the overall objective. The most powerful tool for making minds is technology; not technology as think we know it but the making of meaningful marks. These may be letters, numbers, or other drawings. Children do not express their ideas by cutting and pasting pictures but by creatively writing and drawing. They do not write by taking whole words from a dictionary but by creating them letter by letter. This brings us back to a theme in Eurolog87: Logo in Primary School and to a particular presentation: Teacher's Profile in its Relation to the Attainment of Specific Objectives in a Logo Environment. This may be recast in terms of how programming (writing for the computer as an audience rather than for the teacher to correct) might contribute to overall literacy and numeracy; and what are the prerequisites for a teacher to possess the capability to work this way?

Throwing down the gauntlet to the traditionalists

Primary education is the foundation upon which all learning is built. It must be broad, balanced and strong. The teachers who help children to build their minds must employ the best methods and materials if the foundation is to be sound. At present the book, the old town of Caxton, offers little assistance to the beginner. This poor learning medium makes the apprenticeship in literacy and numeracy extremely onerous. Teachers have had to devise a multitude of techniques to work around this fundamental defect. Success in literacy correlates most highly with experience with text (Adams date). This may be achieved most readily by using a keyboard and the interactive capacity of a multimedia computer. Programming, where text is active, is an obvious entrée to the world of literacy and numeracy for the beginner. The implication is that teaching method and materials need to undergo a massive change. In 1987 the materiel was unavailable. It is now. The computer is the new educational medium. The children's wait for change should be over.

- The constructionist community has provided a curriculum for teaching mastery of the medium; with software written in Comenius Logo and a teacher training course.
- There are two serviceable implementations of Logo that can provide an appropriate environment for children from kindergarten through school.
- The first step is to challenge the institutional failure systematically to teach children mastery of the medium that has become the city surrounding the ancient town of Caxton.
- The second step is to challenge the educational establishment and expose the traditional teaching it methods promotes and employs as inefficient, abusive, and failing.
- The third is to forget projects and focus on the sustained research and development needed to implement method transition in primary school. The final result of relegating the old book technology and using the computer first will be to make the book accessible and enjoyable.

We have steadily retreated into our ghetto since 1987. It is time to recapture the spirit of that time and, choosing our ground carefully, to challenge thoughtless traditionalism and displace it.

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Preparing Teachers to Use Laptops Integrated to Curriculum Activities: the experience of One Laptop per Student project at Unicamp

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Abstract

The objective of this paper is to describe the process of preparing teachers at schools that are receiving the educational laptops (also known as the US$100 laptops) as part of the One Laptop per Student Project, developed by the Ministry of Education in Brazil.

The article describes the structure of the training plan which is being implemented and, specifically, the training of teachers from four schools in the state of São Paulo. Teacher training at these schools is under the responsibility of Universidade Estadual de Campinas (State University of Campinas - Unicamp). These teachers are gradually appropriating the laptop resources and as part of their training, are working with students using laptops in the classroom and in different school spaces, and exploring different school curricula.

Keywords

Project UCA, one laptop per student, educational laptops, teacher training, Unicamp

Introduction

In 1968 Alan Kay presented an idea that seemed impossible: every child should have his/her own computer. Kay put forward this idea right after having visited Seymour Papert at the Massachusetts Institute of Technology (MIT), who was beginning his work with Logo. Kay was impressed by the fact that the children were using the computer to solve complex mathematical problems, and understood that every child should have his/her own portable computer.

The idea of the portable computer became concrete in 1972 with the Dynabook, which was developed by the Learning Research Group (LRG). Kay created the LRG as part of the Xerox Park laboratory (Kay, 1975). The Dynabook can be considered one of the precursors of current laptops. According to Kay's conception, this tool should be a portable computer that is interactive and personal, and as accessible as books. It should be connected to a network and offer the users word-processing, images, audio, and animation. Laptops today have all the characteristics described in Kay's vision.

The idea that every child should have his/her own computer became real in 1989 when the Methodist Ladies' College in Melbourne, Australia proposed that every child in 5th grade should have his/her own personal computer. This experience extended to the other grades until all the students from 5th to 12th grade had their own laptops (Johnstone, 2003). The "P" in the term "PC – Personal Computer" was taken seriously, and the computers were literally personal (Sager, 2003). Since 2001 many schools and educational institutions in the United States of America have implemented the one laptop per child – known as 1-1 laptop, or 1-1 computing.

The arguments used to justify the 1-1 scenario, in general, consider improvements in the student's behavior and disciplinary issues, performance on national or international assessments, social inclusion of students who are socioeconomically disfavored, and preparation for the work force.

However, the ideas Kay developed concerning learning environments are in fact not yet being implemented; much to the contrary. As noted by Kay, the way in which, for example, science is treated in school has nothing to do with doing science. The student does not have the opportunity to deal with uncertainties, to question, and to work with incomplete or imprecise models; challenges that can be debugged with the help of technologies, classmates, teachers, and specialists (The Book and the Computer, 2002). In general, computers are used to access already confirmed facts, and to replicate much of what already happens with a pencil and paper. This can be seen in many of the studies that discuss implementing laptops in schools.

The *UCA* Project (*Um Computador por Aluno* or One Computer per Student) being implemented by the *Ministério da Educação* (Ministry of Education - *MEC*) in Brazil envisions, amongst the changes that will take place when implement this technology in schools, a change in the way in which curricula is approached in the classroom. This does not mean a change in the curricula itself or a change in the content; rather, this new pedagogical approach considers the possibility of the student experiencing the ideas presented by Kay. For example, the student would do science rather than study accumulated knowledge in the field of science. However, as Kay already mentioned, the simple presence of technologies does not guarantee the necessary and desired pedagogical changes. In addition to the presence of the technology, it is necessary to train teachers so that they are able to integrate laptops into their curricular activities.

The *Journal of Technology, Learning, and Assessment* dedicated the entire January 2010 issue to the theme of the use of laptops in a 1-1 situation (JTLA, 2010). Other works try to synthesize the results of various articles published on the subject (Penuel, 2006). The results in the different experiences described are not 100% favorable: some aspects of the projects present considerable gains, while as other aspects of the use of laptops in a 1-1 situation do not bring about significant improvements.

However, it is important to note that teachers are mentioned in practically all of the studies as having a fundamental role in the implementation of laptops in schools. For this to happen, teachers must receive training on how to use the laptops, on how to develop learning projects that are centered on the student, to become better prepared to help students, and on how to create a learning environment that is favorable to the use of this technology.

A positive aspect is that if this training is effective, impacts become apparent in different situations. Those teachers who are better prepared may come to view the laptops' use in a more favorable light. The teachers also become more able to track the students' progress, and understand how students apply curricular content to problem solving situations (Penuel, 2006; Windschitl & Sahl, 2002).

Therefore, the objective of this article is to present and discuss how teacher training is taking place in the schools affiliated to the *UCA* Project. This training is under the responsibility of *Universidade Estadual de Campinas* (State University of Campinas - *Unicamp*). Our aim is to discuss the structure created for this training, and how the teachers are working with both the researchers from Unicamp and their own students in the classrooms. The following sections provide a brief description of the *UCA* Project, the methodologies used to train teachers in the schools affiliated to the *UCA*-Unicamp Project, and the results of this training. The latter is done through a discussion about the ways in which teachers have implemented the laptops in their own classrooms.

The “Um Computador por Aluno – UCA” Project

The *UCA* Project anticipates the deployment of educational laptops in schools, as well as a preparation of teachers and administrators for the use of this equipment with students during educational activities. This is a pilot initiative developed by the *MEC* in 2010 to be under the responsibility of the *Secretaria de Educação a Distância* (Secretariat for Distance Education - *SEED*). With the extinction of *SEED*, in 2011 the Project was transferred to the *Secretaria de Educação Básica* (Secretariat of Basic Education - *SEB*).

The *UCA* Project’s objective is to promote an improvement in the quality of education, digital inclusion, and the Brazilian computer industry’s participation in the development and maintenance of the equipment. Considering the work that had been taking place in the field of the use of technology in education, particularly the work being done with desktops in school informatics labs, the *UCA* Project is innovative in many ways. For example: the use of the laptop by all the students and educators in public schools in a context of immersion into the digital culture; the mobility to use the equipment in other environments inside and outside of the school; the connectivity by which the laptops can be used for teachers and students to interact by means of the wireless Internet connection; and the pedagogic use of the different medias available in the educational laptops.

The *UCA* Project was conceived by a group of technicians from *SEED* and the *Grupo de Trabalho UCA* (UCA Work Group - *GTUCA*), which is made up of research specialists in the area of the use of Information and Communication Technology (ICT) in education from the following universities: UFRGS, USP, UNICAMP, PUCSP, PUCMG, UFRJ, UFSE, UFC, UFPe. These universities are called *Instituições de Educação Superior Globais* (Global Institutions of Higher Education - *IES Globais*). The *GTUCA* participants developed the document with *UCA* Project Objectives (Princípios, 2007). *GTUCA* was then subdivided into three working groups responsible for the development of the following three documents respectively: Development and Monitoring, Evaluation, and Research.

The process for implementing the *UCA* Project began with the purchasing of 150,000 laptops in 2007. This purchase was made through a national bidding, where the winner was the ClassMate brand laptop, developed by Intel and produced by a Brazilian company.

Approximately a total of 350 schools were selected, and these are spread out amongst the 27 States. Roughly 10 schools were selected per State: 5 municipal schools, selected by the *União Nacional dos Dirigentes Municipais de Educação* (National Union of Municipal Education Leaders – *UNDIME*); and 5 State schools, selected by the respective *Secretarias de Educação Estadual* (Secretariats of State Education). In six municipalities (Barra dos Coqueiros/SE, Caetés/PE, Santa Cecília do Pavão/PR, São João da Ponta/PA, Terenos/MS, and Tiradentes/MG) the UCA-Total was implemented, in which all of the schools in each of these municipalities become part of the *UCA Project*. The 350 schools were selected with the intent of complementing different types, such as urban, rural, indigenous, and etc. Each school could have no more than 500 students and teachers. The *MEC* delivered laptops and a server to each school, and each school was then responsible for providing infrastructure such as space, electricity, internet, and closets for storing the equipment and charging their batteries.

Teacher and administrator development was based on the proposal “*Formação Brasil*” (Brazil

Training), elaborated by the *GTUCA* subgroup Development and Monitoring. In order for this training proposal to be implemented a network of universities and *Núcleo de Technologia Educacional* (Education Technology Nuclei - *NTE*) was created in each State. *Global IES* created teams of researchers and interns on fellowships from the *SEB/MEC* to be responsible for the preparation of local training teams, which were in turn responsible for implementing teacher and administrator training at the schools. The training teams were made up of researches from the State's universities (*IES Locais;* Local *IES*), professors at the respective Secretariats of Education, and NTE. The local training teams are responsible for teacher and administrator training at the 10 schools in the *UCA* Project in each State, including those with UCA-Total. Another form of participation anticipated for the training process was that of student-monitors or interns, who would be prepared to give technical support to the teachers at the schools.

Methodology used for the teacher training in schools affiliated to the *UCA*-Unicamp Project

The activities of the *UCA* Project that took place in 2010 and 2011 had the objective of implementing the Project in the schools, and training teachers and administrators in the schools to use educational laptops with students during activities for learning and teaching (Projeto UCA-Unicamp, 2010).

The *UCA*-Unicamp Project corresponds to the *UCA* actions developed under Unicamp's supervision in three Brazilian States in the Northern Region of Brazil (Acre, Rondônia, and Pará), and in four municipal schools in the State of São Paulo, as described in Figure 1.

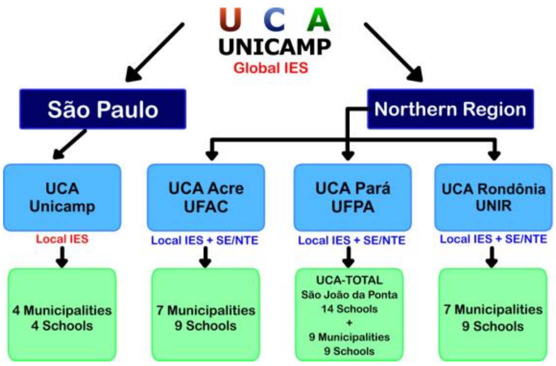

Figure 1: UCA-Unicamp Project Structure: states, universities, municipalities, and schools involved

As seen in Figure 1, the *UCA*-Unicamp Project is acting in schools in the State of São Paulo, and in universities in the Northern Region of Brazil, in the States of Acre (AC), Rondônia (RO), and Pará (PA). It carries out activities with teams at local universities – UFAC, UNIR, UFPA – which are responsible for the *UCA* Project activities in their respective States. These universities, in partnership with Municipal or State Technology Nucleuses and Secretariats, carried out the implementation of the *UCA* Project in schools, as well as teacher and administrator training. In this article we will highlight some of the activities and results obtained in the *UCA*-Unicamp context of the State of São Paulo.

The *UCA*-Unicamp team is comprised of researchers, trainers, and tutors. In the State of São Paulo the *UCA*-Unicamp carried out activities with 4 local teams responsible for applying the teacher and administrator training at the following schools and municipalities: EMEF Prof. Jamil Pedro Sawaya (São Paulo), EMEF Profª Elza M. Pellegrini de Aguiar (Campinas), EMEF Dr. Airton Policarpo (Pedreira), and EMEF José Benigo Gomes (Sud Mennucci). These schools correspond to a population of about 1503 students and 130 teachers.

In 2010, when the equipment and infrastructure provided by the *UCA* Project became available, the process of implementing the program in the schools began. This reality demanded a large interaction between the various teams (*MEC*, University, secretariats, schools) providing information and support to each school so that they could make decisions. During the second semester of 2010, with a few operational and infrastructural issues having been solved, teacher and administrator development sessions, as well as activities using educational laptops with students, took place. The first meetings involved administrators and teachers at the school, and, gradually, the teachers began to work with the students as part of their training process.

The "*Formação Brasil*" course has five modules of a cumulative total of 180 hours that should take place in a blended manner. The face-to-face activities in the course were scheduled to take place at the school. These involved activities where the teachers were working directly with the students using laptops in the classroom. The activities that took place at a distance, through the virtual environment *e-Proinfo*, anticipated an exchange of experiences by the teachers, where they would share reflections, uncertainties, questions, and debates about their experiences while using the laptops with their students, as well as while studying the theoretical principles involved in using technologies during the processes of teaching and learning.

In general terms, each module encompassed certain content that give direction to the practices teachers and administrators use in schools. These included, for example: the appropriation of technological resources available on the laptop; the use of applications available on the laptops and on the Internet with the intent of integrating these resources into curricular content; the issues related to the administration of ICT within the school's structure; the pedagogy that should be applied in projects that contemplate the specificities of disciplinary and interdisciplinary knowledge; and the last module geared towards elaborating a *Projeto de Gestão Integrado com Tecnologia* (Management Project Integrating Technologies - ProGITEC) for the following school year in each school. The creation of the ProGITEC demands a delineation of guidelines for the use of the laptop in the school, thus encouraging teachers and administrators to make explicit their conceptions, proposals, and discussions regarding the strategies for using the educational laptops in a way that is aligned to the Pedagogical Political Plan of the school.

The local training teams should have adjusted the training proposal made by the *UCA* Project, thus allowing for accommodations that take into consideration the real contexts and conditions of each school at the moment when the training was taking place. Therefore, each training team selected from the training modules content, supporting materials, and activities that were most relevant to the school's context, and added other elements to the training, thus adjusting the training so that it best meet the needs of each group of teachers and administrators.

Results of the training activities in four UCA-Unicamp schools

To exemplify the work dynamic as well as some of the results obtained, we will, in this article, focus on the training and monitoring that took place by the team at Unicamp together with the four training teams at the municipal schools of São Paulo, Campinas, Pedreira, and Sud Mennucci. Between June and December of 2010 five meetings took place with the local teams at these four municipalities with the objective of orienting and promoting an exchange of ideas amongst the teachers and administrators at the four schools. The meetings would assist each team in the process of developing training actions.

The training activities in the schools took place between August and December of 2010, and, throughout the year of 2011, also involved the inclusion of topics from the "*Formação Brasil*" Course. In November of 2010 the activities for the use of laptops in the classroom began, thus favoring an association between theory and practice. During the year of 2011 the training activities were resumed, and the teachers carried out activities that related to the five modules in "*Formação Brasil*." Part of these activities took place in the classroom with their own students. This training work took place at the school. Each school relied of the supervision of one researcher from the *UCA*-Unicamp team that monitored the teacher trainings, and assisted the teachers with the activities related to the topics discussed in the five modules, as well as with the actual use of the laptops in the classroom.

The training sessions in the schools took place weekly and each lasted for an hour. Activities that took place at a distance also complemented this training, and were implemented with the help of the *e-Proinfo* virtual environment. As the teachers, initially, did not have any experience using distance education environments the *e-Proinfo* tool was introduced slowly.

When the *UCA* Project was initially implemented in the schools, one of the challenges faced relates to the teachers' insecurity towards using the educational laptop. The equipment was new, and its use in the classroom by students was an unknown for both the teachers and the administrators. The initial challenges related to classroom management, and to the use of the equipment by the students. These insecurities were frequently manifested in the training sessions, as can be seen in the following testimony:

Z.A.B.S. – Pedreira,SP: I feel insecure. I don't know how it is going to be with all the students manipulating the computers at the same time; what if we have a problem, how will I solve it? Will I be able to handle this?

G.T. – Pedreira, SP: I am very anxious, this is a new project that will give the students many opportunities. However, at the same time I am apprehensive about not knowing how to use the laptop.

During the initial months of the training it was possible to observe a progressive involvement of the teachers and administrators in the activities, thus improving how they used the equipment, *e-Proinfo*, and the Internet. The initial resistance and uncertainty were slowly substituted by a desire to overcome their own personal challenges appropriating the technology. Gradually, rooted by the practical context and exchange of ideas, the teachers began to catch a glimpse of the possibilities of using the educational laptop in their classroom. It is important to note that the initial challenges faced by the teachers were circumvented by the constant acting upon by the professionals at the school (colleagues, administrators, and technicians), who addressed or passed on the questions, and encouraged the teachers. From a technical-pedagogical standpoint, the constant support given by the researcher from Unicamp to the teacher, both regarding the use of the educational laptop and the implementation of the from-a-distance training sessions, was a differential that rooted the engagement of the teachers in the project. This created a space where the teachers accepted the challenge of using the educational laptop in the classroom with their students. Therefore, with time, one can observe that the school teams became more fluent and secure, which influences their motivation to use the laptops with the students. During this process we noted that strategies for using the technology daily in the school's context began to appear, as expressed by one of the teachers at one of the schools:

E.A.F. – Pedreira: Dear UCA colleagues. (05.11.2010). We began to use the laptops with our students, simply an activity for them to explore the Classmate. We have worked in 9 classrooms so far, we are working in stages because the closets are not ready yet, we are charging the laptops' batteries in the informatics laboratory using the stabilizer, 15 laptops at a time, and it is working. The children are fascinated, not to mention the students' abilities. It is a success. Hugs to all!

In the report above, we observe that the process for using the laptops with the students takes place incrementally. The initial activities involved a free exploration of the laptops within the classroom. Some technical-operational strategies were planned to make this activity feasible, such as: scheduling time to use the equipment (due to the need to charge the laptops' batteries), and the support from other people (such as administrators and technology technicians). Such demands were a result of the teachers' initial predictions about what it would be like to manage a classroom where each student had his/her laptop; and predictions about the challenges students would face when using the laptop (due to their young age or lack of experience using computers). Figure 2 shows the use of laptops in the classroom, where one can see the students working in groups and individually, and the teacher provides guidance to the students.

Figure 2: First activities using the laptops with students from the school in the city of Pedreira.

Opposite to some of the predictions expressed by the teachers during some of the initial training sessions, these initial experiences with the laptops in the classroom allowed for some satisfactory results: the students handled the laptop with ease, helped each other, and focused on the activity and exploration of the equipment, as observed by some of the teachers.

M.L.G. – Pedreira, SP: .. The students made us surprised, we did not have any challenges during this class, they only asked for me to check on their work all at the same time to make sure they were doing the right thing.

A.C.S. – Campinas, SP: The students' first contacts with the laptop gave the teachers more confidence, they understood that the students "treat" the equipment with composure, they interact amongst themselves sharing their discoveries, and deal with problems with the equipment in a natural way

The teacher's accounts of success throughout the time when the first experiences with the laptops were taking place, made the other teachers calmer, thus creating an environment of greater security, which is important for the success of this stage, as well as continuity of the project.

The next step in the training was the creation and implementation of scenarios for the laptops' use with the students, in a way that would align with curricular content. This factor, during the initial stages of the training, seemed like a huge challenge. In order to start this new phase, for example, the teachers at the municipality of Pedreira elaborated lesson plans that had specific themes to be address, specific dynamics, and the specific resources on the laptops that would be needed. These plans were created individually or in groups. Some teachers who work with a same grade-level, for example, preferred to create a common lesson plan, as seen in Table 1. In this table one can observe the theme for the project, the anticipated learning objective, the resources needed, and the grade involved.

Lesson Theme	Learning Objectives	Resources	Grade / Year
Poetry by Cecília Meirelles	"Leilão de Jardim" (Garden Auction) Recognizing letters (by finding them on the educational laptop's keyboard). Manifesting creativity (illustrating a section). Improving the ability to understand poetry.	Tux Paint (word processing and stamps)	1st grade
Animals in the Pantanal	Activities that relate the laptop to "Reading and Writing" Searching for information about a few animals that live in the Pantanal. Organizing information in into taxonomy cards (found in the textbook) Collaboration (partnerships)	Internet Books "*Ler e Escrever*" (Reading and Writing)	2nd grade 3rd year
Creating Stories with Fables	Gathering information (interviewing family members), reading and writing essays, working within the genre of fables.	Internet Kword Tux Paint Projector Multimedia	3rd grade 4th year
Pedreira, Porcelain Flowers	History of the city, tourist points, economic sectors, political sectors, educational sectors, cultural sectors, and geographic locations. Production of an essay based on the information found on the Internet.	Internet Kword	4th grade 5th year

Table 1: Synthesis of a few lesson plans developed for the use of laptops to address curricular content.

The testimonies below express some of the important aspects of the training courses for the teacher: incentives for the appropriation of technologies by the teacher; experiencing new pedagogical possibilities together with the students; development of work in groups and spaces for exchanges of knowledge amongst the students; proposals for articulate projects with technological possibilities; and practical activities for the use of technology to help teachers reflect on their pedagogical work.

Teacher C – Pedreria, SP: I believe it was a continuous process, for everything we learned throughout the course made us reconsider our pedagogical practices in order to insert the computer so as to improve the students' learning, in addition to providing us with an incentive to get to know this virtual world.

S. R. M. G. – Sud Mennucci: It was gratifying to create moments that were relaxed and meaningful for the students, for, using the technological tool, we were able to create a project as a team in which the students behaved very well, and did not hesitate to help their classmates solve any questions regarding the use of the technology.

It is still not possible to identify significant pedagogical changes, considering the time in which the *UCA* Project has been implemented in the four schools. However, we have observed that the teachers, in a general sense, have already adopted a new attitude towards their work. There are various indications that important pedagogical changes might take place, changes which demand time and new experiences in order to become concrete. The teachers incorporate new learning spaces, work dynamics, reflect with partners in order to elaborate projects, and exchange strategies. Thus, it is possible to note that there is a general mobilization in order to increment scenarios for teaching and learning. These include: use of the laptops by teachers and students in the school creating an environment of digital inclusion; pedagogical use of different medias available on the educational laptop; connectivity – use of the wireless networks connected to the Internet – allowing for communication and interactions between the students and the teachers; and the mobility to use the equipment in other environments inside and outside of the school. Figure 3 illustrates some of the students using the laptops in the library, in the patio, and carrying out different activities related to the scenario of “social entrepreneurship” taking place within the school.

Figure 3: Dynamics of the use of the laptops in the School José Benigo Gomes, Sud Mennucci, SP

Such dynamics show that activities related to the use of the laptops are no longer restricted to the classroom. Students can be actively engaged in their class-work or pedagogical activities even while not in the classroom or under the teacher’s supervision. One of the benefits teachers noted is that schoolwork is now productive, while as before it was restricted to the classroom. Now, schoolwork and pedagogical activities take place anywhere and at any time, and are no longer limited to the confines of the classroom or the class-period.

Conclusions

The educational laptops (also known as US$100 laptops) are beginning to become part of the reality of some Brazilian schools, thanks to the *UCA* Project, developed by the *MEC*. However, simply installing these laptops in the schools does not mean that they will become a part of curricular activities. For this to happen, it is important to train teachers and administrators in the schools so that they can implement the necessary changes in different aspects of the educational process, such as the school’s space, the class period, as well as curricular activities.

In Brazil, training of teachers and administrators from the schools that are receiving the laptops is being carried out by universities whose representatives participate in a *MEC* advisory committee for the implementation of the *UCA* Project, called *Global IES*. In the case of *UCA*-Unicamp, we interact with universities in the State of Acre, Pará, and Rondônia that work directly with local schools that are part of the *UCA* Project. We are also responsible for training teachers in the four schools participating in the *UCA* Project in the State of São Paulo. For the purpose of this article, we described the teaching training process taking place in four schools in the State of São Paulo.

The results obtained up to the present moment indicate that the teachers are gradually appropriating the laptops as a resource, and, as this takes place, start to use the laptops with their students for activities taking place within the classroom. These experiences with technology within the classroom are still isolated and, up to this point, were part of the activities done during the training process. In addition, teachers have begun to see the laptops' potentials, and understand the different resources that can be used in activities taking place in varying learning spaces within the school or used to explore different curricular content. It is still early to describe the benefits of the use of the laptop for the students themselves. However, there is great enthusiasm on the part of the students, which has been transmitted to the teachers and administrators, thus creating an educational environment where teachers are collaborating, and establishing partnerships with the students. To experience this enthusiasm and to be able to channel it towards pedagogical issues is, in and of itself, a great accomplishment. We hope that these are the first steps towards more profound changes that could take place in schools, and that, through these, we are able to achieve the *UCA* Project's objectives of improving the quality of education, and of promoting the digital inclusion of students within the school context.

Acknowledgements

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Training mixed groups of teachers and students in educational robotics using the studio pedagogical model.

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Abstract

This paper presents an introductory robotics training program for teachers and students. The training adopted the "studio" pedagogical model. Studio model stems from formal education in architecture and is consistent to constructionism theory and learning by design model. It is an intuitive model of learning in cases where the trainees apply complex skills from many disciplines and arts. In the paper, first a basic theoretical background of the pedagogical model is presented and it is explained how this method conforms to the requirements of educational robotics and the conditions of this specific training program where students and teachers are simultaneously trained. Following, the detailed description of the program implementation illustrates its design. Then, the evaluation results, which come from teachers and students, are reported. Finally the program results are discussed and remarks are summarised. The contribution of the study concerns mainly the experimental pedagogical verification of the studio approach to educational robotics training as a fruitful learning model consistent to constructionism.

Keywords

Educational robotics, professional development, studio pedagogical model

Introduction

It is common belief that educational robotics provide rich learning opportunities. The application of robotics in education require expensive materials, learning resources, support and training for teachers, so usually it is applied occasionally in the vast majority of schools. Recently more and more attempts of exploitation of Educational robotics in Greek schools are documented. Indicative projects of this kind concern preschool (Fesakis & Tasoula, 2006), primary (Anagnostakis & Makrakis, 2010; Tsovolas & Komis 2010) and secondary education (Fragou, et al, 2010). In addition there are systematic efforts to develop training curriculums in robotics, for teachers. These curriculums include courses in University departments of primary education for pre-service teachers (Anagnostakis, et al, 2008) and professional development programs for secondary education in service teachers (e.g. the TERECoP project Alimisis et al, 2010; Alimisis, 2009; Papanikolaou, et al, 2007), which provide important conclusions and experience for every new attempt in teachers' training for robotics. The existing programs usually underpin the use of workshop and hands-on approaches for training. This paper presents an innovative program for professional development (for teachers) and training (for students and teachers) in educational robotics which uses the studio pedagogical model. The program is short-term (lasts 12 hours), introductory, and aims to familiarise students and teachers (simultaneously) with basic concepts and techniques of educational robotics. The studio pedagogical approach adopts the model of "architectonic studio" (Tripp 1994; Clinton & Rieber 2010), it is consistent to constructionism learning theory and supports the "hands on" approach suggested by the bibliography. In addition the studio pedagogical model utilizes the idea of apprenticeship of less experienced "technicians" to experienced "masters" (the students/teachers trainees and trainers correspondingly in our case) in basic aspects of robotics (e.g. construction, programming and composition).

The paper presents first the studio pedagogical model, continues with the training implementation then reports the assessment of the program by the participated teachers and the students and finally discusses the results and summarises the remarks.

The Studio Pedagogical model

The studio model is common in the formal architecture education where students are often involved in learning oriented to design. The method originates from the architectural workshops (studios) of renaissance, where many craftsmen and artisans were working on teams under the supervision and guidance of experienced masters to create different artefacts in painting, sculpture etc. The apprentice craftsman in architectural studios could work in several art teams, in the same studio, under the direction of corresponding masters until he/she finally choose the art which best fits to his/her capabilities.

The choice of studio model is based on the fact that the construction of a new robot is mainly a design process, which requires the application of several sets of skills, concepts and capabilities which correspond to different arts and disciplines (e.g. design and mechanical construction of the device, programming, interaction with the environment with sensors and signal processing, knowledge from the application field, physics, and mathematics). The studio professional development model is documented in the international bibliography (Tripp 1994; Clinton & Rieber 2010) to such an extent and abstraction level as to be applicable in situations other than its origination. The studio pedagogical model except from the schools of Architecture is also proposed for other fields which deal with technology design like software engineering and educational design.

According to studio model the training is taking place in a laboratory (the studio) equipped with tools, materials, design models, plans and experienced masters (as trainers and directors). In the studio the trainees can practice individually and collaboratively on authentic projects for external "customers". The working hours are flexibly defined in the sense that the students can practice and study both on scheduled sessions or whenever they choose to.

Description of the training program

The training program called "We create Robots in Rhodes" was organised by the Municipality of Rhodes city in Greece. The target group were students and teachers from local primary and secondary schools. Its aim was the familiarisation of students and teachers to educational robotics in order to create groups to participate in the Greek robotics contest organised by WROHellas, as national qualifier to the World Robotics Olympiad. The scientific coordination of the program has been entrusted to the Learning Technology and Education Engineering (LTEE) Laboratory of the Department of Pre-school Education and Educational Design of University of the Aegean. The project coordinators and designers were Prof. Angelique Dimitrakopoulou, and Dr. Georgios Fessakis. The course was supported by the non-profit organisation WRO-Hellas (official organiser of the Hellenic Educational Robotic Contest), the county of Dodecanese and the Technical Chamber of Greece/Department of Rhodes.

Organisation of training

The Stavros Niarchos Foundation (SNF) donated to the Municipality of Rhodes 50 LEGO Mindstorms (code 9797) robotics sets for the needs of the training. Every participating school received 2 robotic sets for practice during hours out of the training programme. The donation also included 4 robotic sets for the needs of the trainers, an interactive white board and a video projector. The training was designed to take place in four computer laboratories in which 6 trainers could support 120 people (students and teachers) maximum. Finally 15 schools and 78 trainees (20 teachers and 58 students) participated after an invitation of Municipality of Rhodes to the local Schools forming 20 groups of 3-5 persons each that could (as a team) participate in the contest. Each team was composed by one or two teachers and 2-4 students. The 20 teams were divided in 3 computer labs equipped with fast internet connection, video projector and 6-7 working tables (Fig 1). Each team also had a LEGO Mindstorms robotic set and a laptop. Finally, 2 trainers were available in each computer lab.

Figure 1. Typical computer lab of thetraining

Figure 2. Teams during the training

The schedule of the training

The training was held in four meetings, of four hours duration each (10:00-13:00) every Saturday from 20 Feb 2010 throughout 13 Mar 2010. In the first 3 meetings both students and teachers (Fig. 2) participated. Students and teachers were trained in educational robotics. The participants had no or very limited previous experience. In addition the teachers were trained to take the role of the future coach of his/her students' team. In the last meeting only teachers participated to learn about the contest organisation details and procedures. So the net duration of the training on robotics was 12 hours. During the scheduled training the groups of students and their teachers-coaches were engaged in learning activities in order to get familiar to educational robotics under the supervision of experienced computer science teachers who had the role of master craftsmen.

For the authenticity of the project the role of the "customer" had been assigned to the Greek Educational Robotic Contest, which required from the students to design and construct a robot for a specific mission. The students could study and practice on the scheduled meetings of the training as well as in time of their choice using sets of robotics and accompanying learning material that had been provided by to their schools.

The brief syllabus of the program follows:

1st meeting: a) Introduction to robotics; b) Introduction to materials, sensors and microprocessor; c) Construction of first robot, which was common for all teams; d) Programming of the first robot without the use of computer.

2nd meeting: a) Completion of the construction of the first robot; b) Programming the robot with LEGO Mindstorm programming environment

3rd meeting: a) Solution of basic robotics' problem (e.g. line follower, maze, obstacle avoidance); b) Creating our own robot; c) Evaluation of the training by students

4th meeting: a) Answering teachers' questions; b) Informing teachers about the Greek Educational Robotic Contest.; c) Evaluation of the training by the teachers

For the training needs, learning activities were designed and developed using resources from the LEGO sets, and available in the bibliography. The teachers and the students were also guided to various internet sites related to robotics in order to be able to continue learning after the training.

Training Evaluation

For the training program assessment three different questionnaires were designed, for the teachers, the students and the trainers correspondingly. Illustrative results and their interpretations from these questionnaires are presented in this section.

Teachers' assessment of the program

Fig. 3 summarizes teachers' answers on queries Q1-Q5 concerning their satisfaction of the training program. From the answers we can support that the teachers are fairly satisfied from the training in general (Q1) and most of them (13/19) are completely satisfied both in general and according to students' learning outcome (Q2). The teachers show satisfaction with the LEGO robotic sets (Q3) and with the trainers (Q4). Finally, they are fairly satisfied with the computer labs (Q5) despite the fact that they suggest bigger labs. The Q6 asked if the teachers would participate again in robotics training. Most teachers (16/19) answered that they would participate again, 2 didn't answer and only one teacher answered negatively.

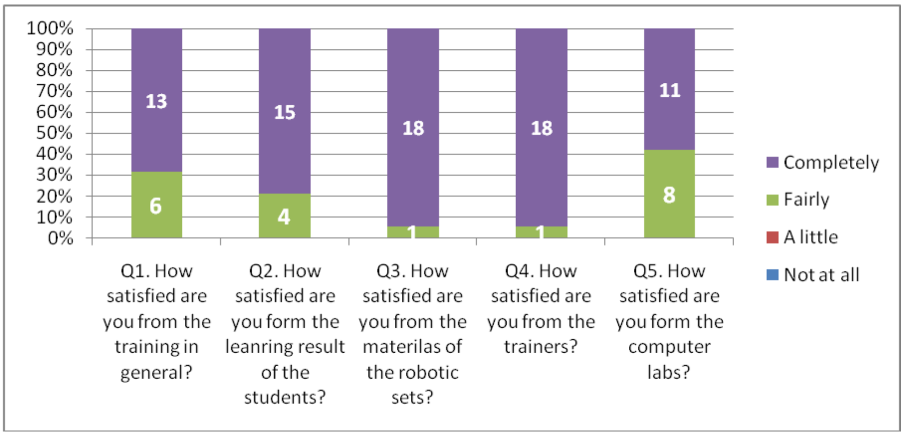

Figure 3. Teachers' answers in Q1-5

Q7. Is educational robotics developmentally appropriate for students?

In Q7 teachers were asked to state whether they find educational robotics developmentally appropriate for their students. Teachers asked to think if it is too easy (so the students will lose their interest) or too difficult (so the students will be discouraged), and furthermore whether it has any learning interest. Most teachers (15/19) answer 'yes' and assume robotics developmentally appropriate using arguments like:

- *Robotics could help to achieve goals of Computer Science, Mathematics and Physics curriculums.*
- *Robotics encourages creativity, inventiveness and self-acting.*
- *Robotics support experimental learning, students initiative, creativity and critical thinking*
- *It is not difficult for the students*

Two teachers (T12 and T15) notice that the robot programming needs a special approach for the younger children

Q8. Comment the appropriateness of training method

In Q8 teachers comment on the appropriateness of the studio model. The teachers recognize that the studio model was student-centred, experiential, collaborative, exploratory, and problem solving based. They also stated that the method is appropriate for students. Furthermore, the separation between robotics construction training from their programming (as different arts) is a good choice (T12). Finally there are proposals like:

- *The participants in each laboratory must be at the same level of education (T3)*
- *The trained students should become trainers assistants on future trainings (T4)*

Q10. What was the most difficult part of the training for you and the students?

The main difficulties that are stated by the teachers are

- The programming (T4, T6, T7, T8, T13, T14).
- The design-construction of a new robot (without instructions) (T15, T16, T18).
- The assembly – construction of the physical parts of the robots. (T1, T10, T16, T18)
- The short available time for practice (T19)
- The design of the robot for the contest (T2, T15)

Q11. What was the most attractive part for you and the students?

Attractive elements of the program as they were mentioned by the teachers, except of the challenge of programming and constructing robots, include: the collaborative and peer form of teachers and students participation, the effectiveness of the method (goals achievement), the joy of the practice, the creative character of the activities, the challenge of discovery, the simplified approach of robotics which usually requires long studies, and the authenticity of robotics curriculum applied.

Q12. What are the aspects of the training that you and your children didn't like?

As negative points of the training, the teachers mark the small size of the labs, the short duration and the small number of available construction materials.

Summarizing teachers developed and expressed quite positive views for the training program and the studio method. Furthermore teachers propose improvements and extensions for future versions of the program.

Students' assessment of the program

In this section students' assessment and ideas after the training are presented. Students answered a questionnaire of closed and open questions the most significant results of which are following. Fig. 4, summarizes the answers of students to questions Q1-Q5 which concern their satisfaction of fundamental aspects of the program. The students are satisfied from the training in general (Q1) and from the constructions of the robots (Q2). They are also satisfied both from the trainers (Q4) and from the robotics material (Q3). Some of them (8/50) are little satisfied from the labs that held the training. We concluded from their answers and from the answers of the teachers that the available space per group should be greater and maybe a specially designed working table could improve the experience even more.

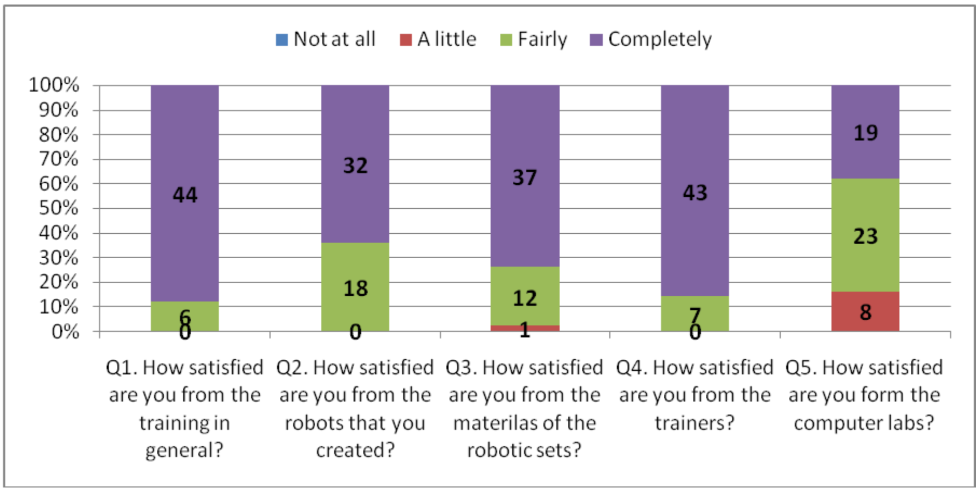

Figure 4. Students' answers in Q1-5

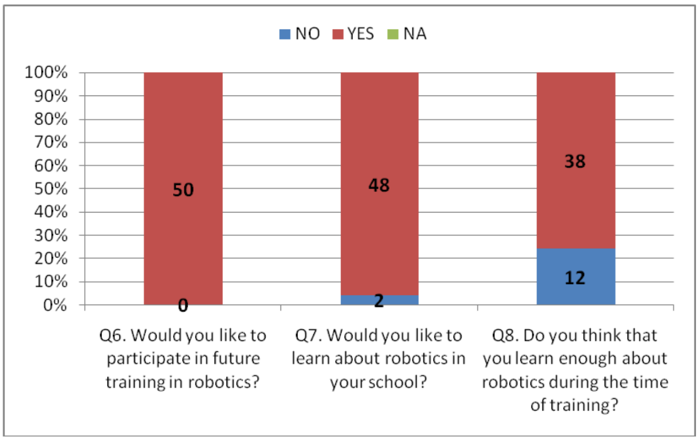

Figure 5. Students' answers in Q6-8

Fig. 5 summarizes students' views about their participation in the program. All students want to participate in future robotics training and the overwhelming majority of them want to learn robotics at school. In Q8, 12 of 50 students answered that they do not know enough about robotics; it seems that the introductory training created more questions than those it answered.

In the following, the answers of the students in open questions are categorized and presented to inquiry their ideas about robotics after the program.

Q9. What I learned...

Most students (41/50) answered the obvious: *Construction and Programming of robot.* On the other hand there are four answers which refer to collaboration skills and other abilities like: *working with patience, not to give up trying, improvising,* which are indicative to learning load of working with robotics

Q10. What I liked most...

Most students reports the construction (19/50) or/and programming (12/50). It seems constructing is more pleasurable than programming, for children. There are also 7 enthusiastic students who like everything. Especially we notice references to

- Robotics parts and materials, sensors, and motors.
- Characteristics of the learning design of the program: *the videos, the problems that were solved by the robot, the creation of our own designed robot the last Saturday of the training.*
- Qualitative social and emotional characteristics of the activities: *Collaboration, the whole experience.*

Q11. What I did not like...

The students did not like the lack of space of the labs (7/50), the foreign language of the software (1/50), the programming difficulties (3/50), the robots construction part (1/50), and the material of the set (2/50). Most of the students (28/50) answered "nothing".

Q12 What made it difficult to me ...

The students found difficulties in construction and/or programming while 3 of them refer that they couldn't find ideas for their own robot in the last meeting (Table 1).

Frequencies	Answers
19	Nothing
13	Construction
12	Programming
3	Ideas for my robot
2	NA
1	The material because it was unbowed

Table 1. Q12 What made it difficult to me...

Q17. I would like to construct a robot to…

The students' imagination as it is expressed by the answers (most answers are in Table 2) is impressive. Most students like robots with human abilities e.g. to study for them, to do the housework and to be absolved from time-cost and boring tasks in general. Also, some of them like a robot to be a friend, an assistant, surgeon, rescuer and older people assistant. Furthermore, we have proposals concerning animals e.g. dog, scorpion, and turtle. In the next category we have mechanisms performing difficult or useful works, which sometimes are artistic (play music, paint), sometimes are utilitarian (garbage collector, gardener) and sometimes just perform a single job (climbing stairs, walking on walls, solving the rubric cube). A student said that he would construct a robot with his friends, which means that he believes that the robot construction is entertaining.

Frequencies	Answers
8	Study
6	Do the housework
4	Abstract
4	Walks
3	Assistant
2	Surgeon
2	Solves the Rubik Cube
2	Plays music instruments
2	Scorpio
2	Friend
1	Climbing stairs
1	Gasoline vehicle with electricity
1	Older people assistant
1	Huge human
1	Rescuer
1	Floats on water, avoids obstacles
1	Paints shapes
1	Wins the contest
1	Garbage collector
1	Ecologist
1	Plays with a ball
1	Gardener

Table 2. Q17 I would like to construct a robot to…

Q14. A robot looks like...

Exploring the students' ideas about robots we see (Table 3) metaphors like humans-assistants-friends featured by anthropomorphic characteristics which are rather expected because of their existing mental representations (mainly from movies). Furthermore we observe the ideas of a car or an animal. Finally, there are ideas like a machine, small creatures, even UFO.

Frequencies	Answers
25	Human – Assistant – Friend
10	Car
9	Animal (Dog, Scorpio, Turtle)
4	NA
1	Remote control
1	Anything
1	Engine
1	Small creatures
1	As you can imagine them
1	Spaceship

Table 3. Q14 A robot looks like

Summary

As we can see from the answers in questionnaires, we can state that pedagogical method "Studio" which was used in the program had fairly positive results both to teachers and students. This means that the training was fairly successful. The teachers are very satisfied from all sides except from the available space in the labs where the training took place. It is very important that the majority of them assume that the learning result of their students was quite satisfactory, confirming our choice for the pedagogical method, and would like to participate in future trainings. The students also evaluate the training positively and just few of them point out the small size of the labs. It is very encouraging the finding that the students learnt not only to construct and to program a robot but also to collaborate, to work with patient, to improvise and not to give up trying.

The success of the studio model relies on the fact that the educational robotics requires skills for design and synthesis of complex constructions combining several arts and disciplines. Obviously the development of such skills requires a pedagogical method which utilizes experiential and empirical learning and exploits the apprenticeship to more capable peers and collaborators. Using the studio model students and teachers had the opportunity to get familiar with a diverse set of skills in a rapid and more intuitive manner than a linear training program that would present every relevant aspect in a sequential mode without the scaffolding of the trainers.

All the above are sealed by the successful participation of four groups in the Greek Robot Contest, which had been organized by the WRO Hellas the summer of 2010. More specifically, the team of 2nd Vocational Lyceum of Rhodes with trainer Mr. Dimitrios Kladogenis won the first place in its category. The group represented Greece in the International Robotics Contest which held in Filipinas (Philippines) in November of 2010 and took the 15th place among 48 teams from all over the world.

The educational robotics as a course which combines the science with the mechanics, the ICT and the creative design deserves to be studied more from the view of its educational applications. The training team plans to invest in the experience to promote more the educational applications of robotics. Furthermore, the pedagogical method studio can be applied to other subjects in future, like the pedagogical training of the teachers and the educational design with ICT.

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A Constructionist Method for Teaching Teachers about Basic Properties of Complex Systems, using a NetLogo Model.

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Abstract

The current research report discusses a Constructionist approach used to teach prospective Greek Primary School Teachers, about five certain properties of Complex Systems (CS's), by the use of the programming and modeling environment of NetLogo, and especially by the use of a NetLogo Model called "Ants". The research presented here was part of a broader research project, which had as ***central research question****: if and to what extend the NetLogo models can help future educators conceptualize specific properties of Complex Systems in nature. Students underwent approximately one-hour-lasting interviews, by the first of the authors, which were fully recorded. The whole interview was taking place in front of a computer, which had the NetLogo Model "Ants" activated, as well as some variations of it, created by the researchers. The students interacted with the model all of the time, in a constructionist manner of learning and discussing, and in an inquiry-based-learning strategy, so as to complete the interview.*

After the thorough examination of the results obtained by the interviews, it becomes evident that: the use of the NetLogo Model helps undergraduate Primary School Teachers conceptualize five basic properties of the Complex (Adaptive) Systems, and to build a representation of the comportment of these systems on their own.

Keywords

NetLogo, undergraduate teachers, teaching, complex systems.

Introduction.

The core idea behind constructionist teaching, which is learning-by-making (Papert and Harel, 1991, Papert, 1980), as well as working with the learner with a not-so-much predetermined plan, but changing the teaching methodology according to the feedback that the teacher receives in each step of the teaching sequence, is optimally applied by the use of computers. (Kafai &

Resnick, 1996). The use of the Logo-like environments is appropriate for involving the learner in activities which would lead him, with the instructor only as a mediator, to the cognitive results aimed at, as much of the literature proves (Healy & Hoyles, 2001; Laborde et al., 2006). An environment used extensively in the recent years for teaching learners of various ages about basic concepts of Mathematics and Science, is NetLogo (Wilensky, 1999). NetLogo is a Multi-Agent-Based Modeling and Programming environment based in the Logo language as invented by Seymour Papert, and to the StarLogo Microworlds as invented by Mitchel Resnick. The use of many "turtles" (agents), the number of which is determined by the user, as well as the user-friendly interface makes NetLogo an ideal tool for instruction, especially for the conceptualization of complex systems (Tisue & Wilensky, 2004). A lot of research has been carried out on what exactly "conceptualization of complex systems means" (Jacobson, 2001) and more specifically what shift in the person's way of thinking this requires, and to what aspects of the system's conceptualization it refers, such as the Structure, Behavior and Function (SBF) (Hmelo-Silver & Pfeffer, 2004). Especially researchers like Sharona Levy have extensively used the programming environment of NetLogo in empirical researches to see how it affects the learners' understanding of Nature (Levy & Wilensky, 2008; Levy & Wilensky, 2011). In this research, the model "Ants" from the NetLogo Models' Library was chosen, since it addresses a natural-like system that is both **complex** and **adaptive,** like many other natural systems (Levin, 1998). In addition to this, the Model "Ants" – which also exists in StarLogo (Resnick, 1997) – helps the learning subject develop certain mental qualities. Such qualities are: (i) decentralized thinking (Resnick, 1996; 1998), which means understanding that a system may work without a central control or leader and (ii) thinking in levels (Wilensky & Resnick, 1999), which means realizing that local interactions among members of a system may lead to a totally different and unexpected overall behavior.

The research presented here was part of a broader research project, which had as its **central research question**: "if and to what extend the NetLogo models can help future educators to conceptualize specific properties of Complex Systems in Nature". These properties included **the ones discussed in this paper**, which are: (i) self-organization, (ii) lack of central control or leadership, (iii) emergence of an overall (human-intelligence-like) behavior through local exchange of a simple set of information, (iv) non-repeatability, even with identical initial conditions (stochastic properties) and (v) existence of critical values for certain parameters.

The Sample and the Research Procedure.

The research was addressed to undergraduate students of the Department of Primary Education, University of Athens Greece, who had chosen to be taught the optional course: "Environmental Science and Education: The Laboratory Approach". The Constructionist context of introducing students to Complex Systems (and mainly ecosystems as Complex Systems), consisted in having them in pairs in front of Computers in which the NetLogo Models were installed, and having them trying to find out what the model (here "Ants") does and how they can interact with it. The answers were written on worksheets. This constructionist introduction to the NetLogo Model is explained in APPENDIX .

After the familiarization with the NetLogo environment and with this specific model, the interview with each pair of students followed.

Each interview, during the research process, was aimed at referring to one couple (n=2) of undergraduate students (when it could not be achieved, instead of two, one was interviewed). It lasted one hour to one hour and a half.

The couple started by being acquainted with the NetLogo Model, the specific one being "Ants", by playing with the buttons and the sliders and by watching the screen. Simple initial questions accompanied this procedure such as: "what do you think this button/slider does?" or "what is this that you watch in the screen?" or "what do you notice?" The main questions of the interview had always three phases: (a). Answer before you try it in the model (prediction), (b). Answer after you try the model many times and – if you like – change the parameters (testing) and (c). Compare (a) and (b) and reach a final answer. Also give your explanation why your answer is valid.

Each one of the two students in the couple (when in couples) could discuss with the other in stages (b) and (c).

The specific sample which participated in the interviews were N=15 undergraduate students of the Department of Primary Education of the University of Athens. This sample was part of a larger research sample, consisting of 85 students, who participated in the overall research. All of these 15 students were attributed with specific values for four different parameters, i.e.:

- **Year of Study.** The parameter takes the values: **A, B, C** and **D** (no students of the Department of later years participated).
- **Orientation during the Third (final) Class of High-School**. The parameter takes three values: **Sc** (Science) – did not exist in this specific sample – **Theor** (Theoretical, Classical Studies) and **Tech** (Technological).
- **Whether or not they had chosen Biology as an exam topic for the entry exams to the University**. The parameter takes two values: **Biol-YES (Y)** and **Biol-NO (N).**
- **Whether or not they had chosen Informatics among the optional topics either in the years of the high-school or in the University.** This parameter takes two values: **Info-YES (Y)** and **info-NO (N).**

In the Table 1, which follows, the values of the parameters for each member of the sample that was interviewed are provided.

Student's Number	Year of studies	Orientation	Biology	Informatics
1	3	Tech	N	Y
2	3	Theor	N.A.S[1]	N.A.S
3	4	Tech	N.A.S.	N.A.S
4	3	Theor	N	Y
5	3	Theor	N.A.S	N.A.S
6	3	Theor	Y	N
7	3	Theor	Y	Y
8	3	Tech	Y	Y
9	3	Theor	N.A.S	N.A.S
10	2	Theor	Y	Y

[1] Never At School. This means that some students had **never** the chance to choose this topic, for example students having taken University entrance exams with another system, or students coming from Cyprus.

11	2	Theor	N.A.S.	Y
12	2	Tech	N	Y
13	2	Theor	N	Y
14	3	Theor	Y	Y
15	3	Theor	Y	Y

Table 1. The sample interviewed, with respect to the values of the parameters.

Each pair of students were initially interviewed with respect to the initial "Ants" Model of NetLogo (Wilensky, 1997), with the slight difference that the sliders, the buttons and the rest of the NetLogo interface screen was translated in Greek. This is shown in Figure 1, below.

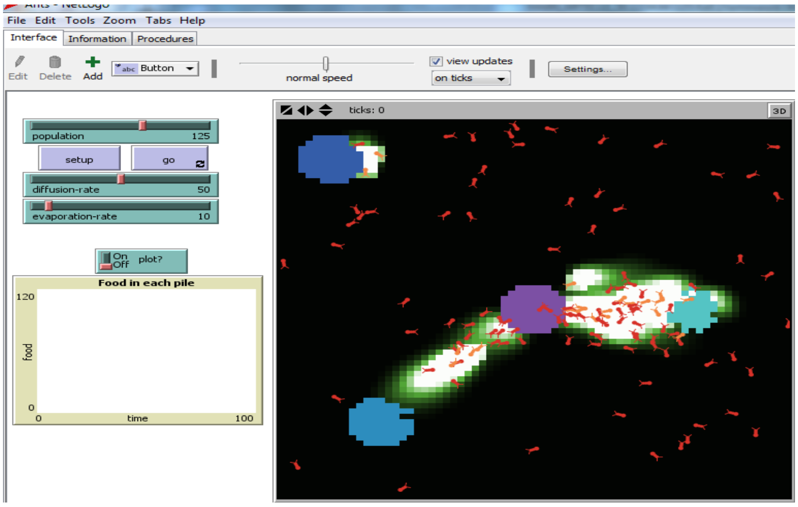

Figure 1. A screenshot of the NetLogo Model "Ants"

At a later stage of the interview, the undergraduate students were asked questions about a variation of the Model "Ants", in which there are *only two* food-sources, identical and *equidistant* from the ants' nest. In Figure 2 below, a screenshot of this Model is given.

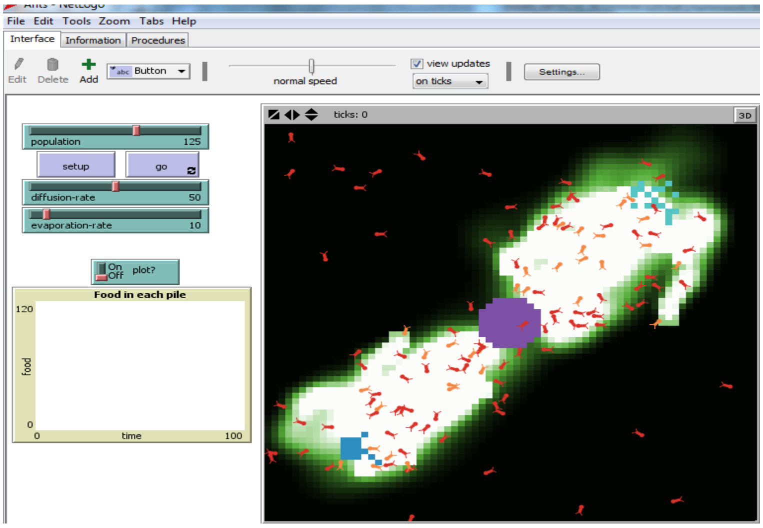

Figure 2. A screenshot of the NetLogo Model "Ants" with ONLY TWO food piles, in EQUAL DISTANCES from the nest.

Finally in the interview, a variation of the Model "Ants" is used, in which there is *only one* food-source, but with *an obstacle* between the ants' nest and the food source. In Figure 3 below, a screenshot of this Model is given.

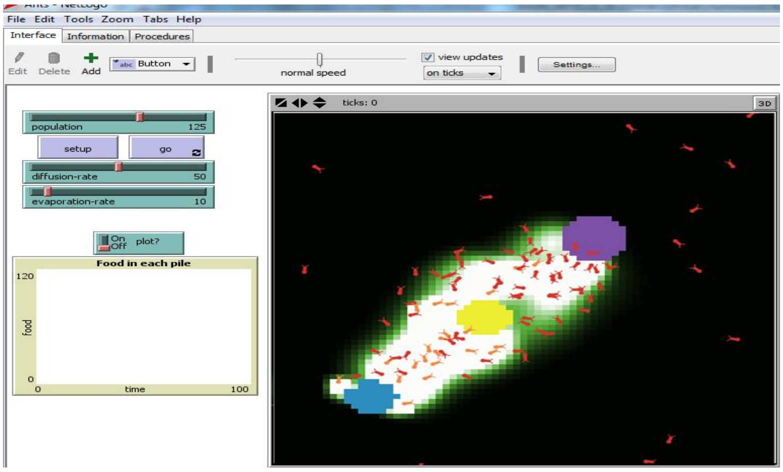

Figure 3. A screenshot of the NetLogo Model "Ants" with ONLY ONE food pile, and AN OBSTACLE between the ants' nest and the pile.

The interviews with the students were conducted in front of a PC screen, with the NetLogo models installed on it, by the first of the authors, and were built within a constructionist framework, combined with inquiry-based-learning techniques.

Simultaneously to this sample, a **control group** was formed with $N_{CONTR} = 8$ untergraduate students. They were also divided in four pairs, they had a similar distribution of parameters with the one given in Table 1, and they gave identical interviews with the initial sample, with one major difference: they did not have a computer and did not interact with the NetLogo Model at all. Instead, the model "Ants" was described and taught to them on whiteboard, step-by-step, by the first of the authors.

Results and Discussion

A. Initial "Ants" Model of NetLogo.

As becomes apparent from the interviews, the students (Question 2, *"Which is the inherent logic of the accumulation of food within the population of the ants?"*) tend to see a centralized control for the ants' troop, as they initially become acquainted with the model. Out of the N = 15 students,

- the $N_1 = 0$, before their further involvement with the model, tend to believe that the first ant that reaches the food-pile, is some kind of leader for the others.
- the $N_2 = 14$ give scientifically "wrong" answers about the role that the pheromone plays (the "white" substance).
- the $N_3 = 5$ have not a clear image of the role that the *number, (the "population")* of the

ants plays in the time-evolution of the model.

- the $N_4 = 5$ are not able to determine what is the effect of the value of the sliders: “diffusion-rate” and “evaporation-rate” to the consumption of the food piles.
- the $N_5 = 2$ seem to believe that the order by which the food piles are consumed will always be the same, no matter how many times the model’s run is repeated.
- the $N_6 = 14$ argue (in various ways) that the fact that the first food pile eaten is the closest to the nest, is statistically explained, i.e. more ants “hit” it, due to proximity.

In the control group, the corresponding numbers were:

$N_{CONTR,1} = 6$, $N_{CONTR,2} = 6$, $N_{CONTR,3} = 6$
$N_{CONTR,4} = 8$, $N_{CONTR,5} = 6$, $N_{CONTR,6} = 8$

But as the constructionist interview proceeded, and they played several times with the model, the numbers clearly improved:

- N_1 remained $N_1' = 0$
- N_2 was reduced to $N_2' = 2$
- N_3 was reduced to $N_3' = 0$
- N_4 was reduced to $N_4' = 0$
- N_5 was reduced to $N_5' = 1$
- N_6 was reduced to $N_6' = 1$.

The results are graphically shown below (fig.4):

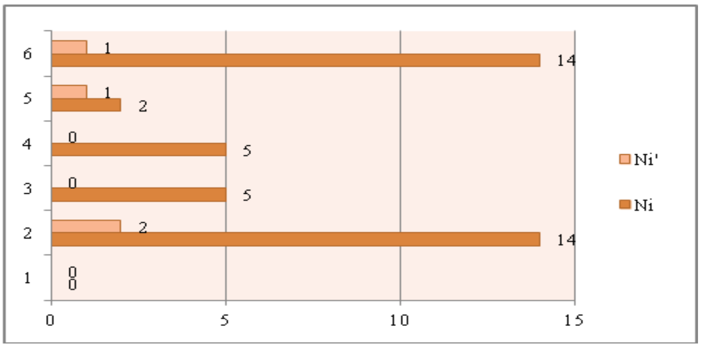

Figure 4. The “answers” before (Nx) and after (N’x) the interview (Model “Ants”)

The corresponding results in the control group were :

$N'_{CONTR,1} = 5$, $N'_{CONTR,2} = 5$, $N'_{CONTR,3} = 6$
$N'_{CONTR,4} = 6$, $N'_{CONTR,5} = 6$, $N'_{CONTR,6} = 8$

Other results stemming from this initial application of the Model “Ants” in the interviews were:

- The $N_5=2$ students belonged to the same group, when the research was carried out in the overall sample.
- The members of the sample who had taken Biology as an optional topic ($N_{BIOL} = 6$ in total) for the University Entrance exams, gave more well-documented and combinational answers, as regards the parameters of the pheromone (diffusion rate and evaporation rate).

- The persons that had entered University in another way (those taking older forms of entrance exams, those moving to the Education Department after completing studies in another Department or people from Cyprus) gave very simplified answers.

B. Variation of the "Ants" Model, with two equidistant food-piles.

In the beginning, out of the N = 15 undergraduate students, only $N_7 = 2$ realized that one of the two food piles will clearly be consumed first. The others thought that they are consumed practically simultaneously, with a slight advance of one of the two. Also, $N_8 = 5$ believed that the pile consumed first is always the same one, or at least in most cases.

In the control group, the corresponding numbers were:

$N_{CONTR,7} = 4$, $N_{CONTR,8} = 6$.

Later, after extensive trials of the model, the numbers improved.

- N_7 increases to $N_7' = 6$
- N_8 falls dramatically to $N_8' = 0$

The results are graphically shown below (fig.5):

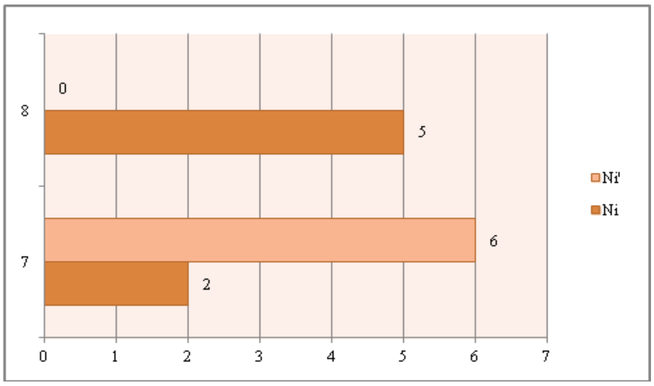

Figure 5. The "answers" before (Nx) and after (N'x) the interview (Model "Ants, variation with two food-piles")

The corresponding results in the control group were :

$N'_{CONTR,7} = 5$, $N'_{CONTR,8} = 6$.

Further analyzing the interviews' results, it could be seen that:

- The $N_7 = 2$ considered both food piles as equally capable of being consumed first, still only one of them, they said, will precede.
- As is obvious both from numbers N_7 and N_7', the prevailing view were always that the two equidistant food-piles would be consumed practically simultaneously.
- Once more, the members of the sample who had taken Biology as an optional topic ($N_{BIOL} = 6$ in total) for the University Entrance exams, gave more alternatives in their answers.

C. Variation of the "Ants" Model, with one food-pile and an obstacle.

In the beginning, $N_9 = 3$ argued that the ants will bypass the obstacle in random ways.

Also $N_{10} = 1$ argued that they will create a curved trajectory in the one side of the obstacle.

Only N_{11} = 2 could see that this curve will be the tangent to the obstacle.
And only N_{12} = 4 were able to see that there will be TWO such identical trajectories one adjoined the obstacle.
In the control group, the corresponding numbers were:

$N_{CONTR,9}$ = 5, $N_{CONTR,10}$ = 2, $N_{CONTR,11}$ = 4, $N_{CONTR,12}$ = 2

Afterwards, the Numbers get much better.

- N9 reduces to N9′ = 0
- N10 reduces to N10′ =0
- N11 increases to N11′ = 12
- N12 increases to N12′ = 8

The results are graphically shown below (fig.6):

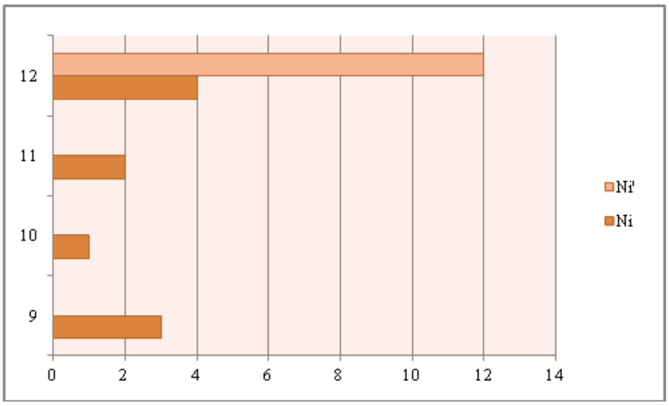

Figure 6. The "answers" before (Nx) and after (N'x) the interview (Model "Ants, variation with one food-pile and an obstacle")

The corresponding results in the control group were :

$N'_{CONTR,9}$ = 2, $N'_{CONTR,10}$ = 2, $N'_{CONTR,11}$ = 6, $N'_{CONTR,12}$ = 4.

- In this latter form of the "Ants" Model, used in the interview process, the students answered mainly based on their experience with NetLogo and on the things they saw with the Models, regardless of their pre-existing knowledge.
- In this part, a great variety of answers were given, combining arguments in many ways.
- Again in this part, the persons that had entered University in another way (those taking older forms of entrance exams, those moving to the Education Department after completing studies in another Department or people from Cyprus), found it difficult to answer in many cases.
- The vast majority of the students coming from a theoretical orientation in high-school (9 out of N_{THEOR} = 11), needed a lot of guidance to formulate an answer.

Conclusions

Initially there are some "case-affected" or technical conclusions from this research: At first, the students coming from a technological orientation in high-school (NTECH = 4), did not encounter any special problem in handling the NetLogo interface, as regards its usage and the understanding of its functions. Secondly, all of the students of the sample (15 out of 15) altered their answers after testing the Models many times, emphasizing on the usefulness of the method. Thirdly, most of the inadequate answers came from the undergraduate students that had entered University with another system of entrance exams, than the one mainly valid in Greece nowadays.

But stress should definitely be given to the more general conclusions, referring to the usefulness and the effectiveness of NetLogo, and this specific model, in the conceptualization of Complex Systems on behalf of future educators.

First of all the 11 out of the 15 students – a percentage of around 73% – towards the end of the interviews had switched to an almost common form of terminology, the one appropriate for Complex Systems and for NetLogo, and they ended up giving well-documented answers.

It should be stressed also that when the undergraduate students were in couples, the answers tended to be much more alike, since the discussion among them affected their views. So we have a definite ***peer-effect*** very common in constructionist methods working in pairs. The same is valid for the four groups of the control group.

As can be seen from the relatively poor performance of the control group, related to the basic sample, NetLogo seems to be a great instruction tool for getting the learning subjects acquainted with the properties of Complex Systems, compared to classical, oral instruction. Complex systems are much better realized when seeing them evolving in time on a screen, and when interacting with their properties, than when being simply taught about them in a series of lectures.

Constructionist approaches and teaching through NetLogo seems to be giving the learners, a better feeling about understanding the subject of Complex Systems, compared to oral instruction. One of the very last questions on the worksheet was: "Was it helpful, in understanding?" and 11 out of the 15 students of the main sample answered positively, as shown in the figure 7, whereas only 2 out of the 8 persons in the control group gave affirmative answer to this.

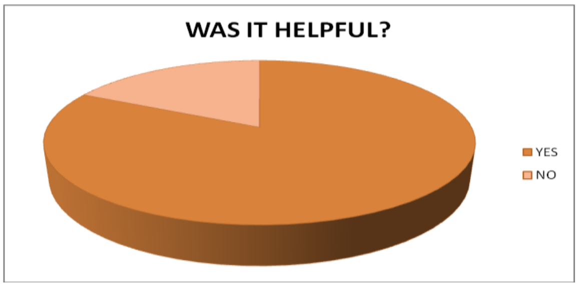

Figure 7. Answers in question: "Was it helpful, in understanding?"

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APPENDIX

The Constructionist set of Questions on the Worksheet, to introduce students to NetLogo Model Ants.

1. What are the buttons that you see on this screen? What do you thing each one is doing? ***(Always write your answers, after discussing within the pair).***
2. Try to press button named “SetUp” once. What is this that you see in front of you?
3. Press “Go”. Can you find out what this troop of ants does? Describe in your own words.
4. What is this white substance doing? Try to give a description, after trying the situation many times (always restart by pressing SetUp and then Go)
5. Do you see any resemblance with real ants? Give a description, after trying the model as many times as you like, altering the parameters.
6. What is shown on the plot, when you have it “on”?
7. What is the overall logic, or strategy, in the ants motion? Can you see it?
8. What do you thing of the buttons “diffusion-rate” and “evaporation-rate”? Try them with many different values to see if you can find out what they are doing.
9. If you work with one ant, and then with very few ants, do you notice any differences? Which ones.
10. In general, do you see if the population of ants plays a role in the situation? If yes, how you would describe it?

Designing and modifying artifacts through actual implementation in mathematics classrooms

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Abstract

This paper reports research aiming to highlight how the design of artifacts with the use of digital tools in mathematics can be informed by the experience of their implementation in real classroom settings. Under a constructionist theoretical perspective, a group of two researchers and a newly trained teacher educator collaborated to explore the distance between design of tasks with digital tools and their actual implementation in the classroom of mathematics. A series of activities related to the Thales Theorem were created and implemented in different classes with the use of Sketchpad. The implementation led to significant changes in both the artifacts used (worksheets, microworlds) and the teaching management. The constructionist consideration of the artifacts as transformable objects facilitated the development of a scenario based on elements that emerged in actual teaching.

Keywords

Transformable artifacts, scenario design, communities of inquiry.

Introduction

Our general aim in this paper is to explore the contribution of constructionism as a design framework in addressing the potential of artifacts with technological tools in mathematics classrooms. The term artifact here describes tasks – and the correspondent worksheets and microworlds – designed as coherent parts of scenarios with the use of technology for the teaching and learning of mathematics. Constructionism as an epistemological paradigm and as a learning theory has been extensively used for designing expressive digital artifacts and studying students' generation of mathematical meanings individually and collaboratively. Over the years constructionism has also been used as a design framework in order to inform research and practice in a range of contexts such as the integration of digital tools in mathematics classrooms and the design and implementation of artifacts and activities by teachers as means for reflection and professional development (Noss & Hoyles, 1996, Kynigos, 2007). A common feature of all these approaches is that they were based on the use of expressive media designed under fundamental constructionist principles (e.g. construction of mathematical meaning through collective bricolage with artifacts, Papert, 1980). However, due to the current proliferation of digital tools for the teaching and learning of mathematics as well as the recently highlighted need for connecting different theoretical frameworks in order to address more efficiently the potential of artifacts for mathematics learning (Artigue, 2009), it seems to be useful to investigate the contribution of constructionist approaches to learning as design in a range of different contexts and computational environments. For example: how a constructionist approach to development and modification of artifacts with dynamic geometry systems (DGS) might influence the evolution of teachers'/researchers' didactical design? This paper reports research aiming to highlight how the design of artifacts with the use of technological tools in mathematics can be informed by the experience of their implementation in real classroom settings. We adopted a broadly constructionist framework in designing and modifying artifacts with DGS (as a kind of 'bricolage') in a collective reflection context involving teachers and researchers. In this perspective, artifacts were considered as malleable objects transformed after reflection on the practices developed when implemented in actual classroom settings. Thus, the reported research indicates a novel approach to developing scenarios for technology enhanced mathematics: from practice to theory.

Theoretical Framework

The study was based on the assumption that the use of digital tools into the educational process requires teachers to undertake an active role in establishing new, enriched curricula, while making meaningful decisions for their students (Budin, 1991). This assumption implies the study and redefinition of the relationship between teachers and mathematics curriculum. When curriculum is referred to, we have to distinguish between the formal, intended curriculum (that which resides in state frameworks, guides, textbooks, and in teachers' minds as they plan what they will do) and what it appears to be, which is curriculum as enacted by teachers in the classroom and curriculum as experienced by students (Gehrke et al., 1992). The teacher - curriculum relationship can be approached through various theoretical frameworks (Remilliard, 2005), the most traditional of which, conceives the teacher as an "implementer" of the formal curriculum. Through this perspective, the clarity and the detailed instructions of curriculum texts aim at a closer guidance of the teacher and his/her dependence on them. However, existing research has shown (Remilliard, 2005) that there is a mismatch between the formal, intended curriculum and the enacted one. This finding emphasizes the importance of the context of implementation and recognizes the significant role of the teacher as mediator on what is planned and what really takes place in the classroom. Very important factors that influence teachers' mediation are their knowledge, beliefs and experiences. From this point of view, the teacher can be perceived as the "interpreter" of the curriculum, a person who has the ability to adjust or reconstruct it, according to his/her students and the learning conditions of each classroom. This "participative" relationship can be achieved through a process of design, during which, the teacher perceives and interprets existing resources and sources of the curriculum, evaluates the constraints of the classroom settings, balance trade-offs and comes up with strategies (Brown & Edelson, 2003). This process also involves enacting the respective plans in the classroom with students and redesign after each implementation.

The so-called "lesson plans" constituted the first step for the teacher's involvement in the design process. They particularly include: the material that has to be taught, the teaching method, the material required, the teaching time and the worksheets. The introduction of new material and theoretical frameworks brought to light new elements related to the learning environment that had to be included in the design, such us students' groupwork, spatial ergonomics, availability of other sources etc. As a result, the lesson plans yielded their position to the "activity plans". The notion of activity, that appears highly upgraded in the current mathematics textbooks of Greek High school, includes students' action upon the development of a specific mathematical concept (Stein et al., 1998).

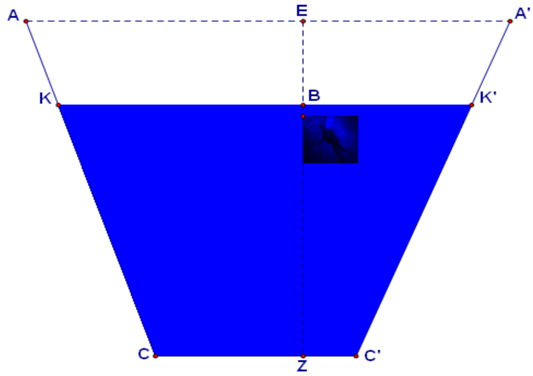
However, the activity plans do not address the complexity of the learning environment, since they are mainly teacher-centred and seem to focus on the didactical sequence of the designed activities rather than on the expected learning processes and the students' expected actions. Over the last years, researchers in technology enhanced mathematics have suggested the educational scenarios as the means to fill this gap. From one point of view, scenarios can be considered as further developments of activity plans. However, current research in the field suggests that scenario development constitutes an in depth penetration into the teaching practice since scenarios include not only the usual topics of activity plans but also references to interrelated activities, as well as teaching, learning, administrative and socio-cultural processes (Laborde, 2001).

Teachers' engagement in scenario design with the use of technology brings in the foreground another parameter of the already complex teaching and learning environment: the technology. This new parameter, perturbs the existing balance of the system student-teacher-subject to be taught (Laborde, 2001), thus the teacher is supposed to determine through a series of decisions if, where and how technology would be used. Since many mathematics curricula have been enriched with activities that include the use of technology, the teachers can chose to implement them as given without making any changes or to modify them or even create their own ones. The way that teachers use technology is closely connected to their beliefs about the role of mathematics' teaching and the way they treat the curriculum's commitments. A scenario that includes the use of technology in mathematics has to provide a documentation concerning a number of crucial parameters of the teaching and learning process such as the students' difficulties with the targeted mathematical concepts and how these difficulties are addressed. Most importantly, a scenario has to describe the way and the form under which technology is going to be integrated. For instance, we consider the idea of half-baked microworlds (Kynigos, 2007). The term was introduced under a constructionist perspective to describe microworlds that incorporate an interesting idea but they are incomplete by design so as to invite students to deconstruct them, build on their parts, customize and change them, eventually constructing a new artefact through the modification of the original one. In designing a half-baked microworld the teacher has to make choices as to what the students are going to do with the available tools and the types of meanings that they are expected to construct through its use. In the present study we found relevant to export the idea of half-baked microworlds to a collective reflection context involving teachers and researchers. In this context, we used the idea of 'half-baked' to refer to artifacts which are considered by teachers/researchers as amenable to changes by themselves after implementation in the classroom through a cyclic process of 'design-implementation-redesign'. Other parameters that also have to be included in the scenario's design are the social orchestration of the class, the time and space aspects of the environment and the teaching management of the activities. In this sense, the process of developing scenarios signifies a change from the teacher as implementer to someone who actively constructs the practice of schooling and strengthens the teacher's professionalism (Carlgren, 1999). The processing of the teacher's decisions during the design (which is the subject of the present study) is considered as an integral part of his/her professional development. The recent teacher educators' training programs in Greece concerning the use of the digital technology in the teaching of mathematics, have led to the development of a series of notable scenarios. However, the majority of these scenarios has been developed theoretically, without being implemented in the classroom. As we see, at least in our country, there is a gap between the design of artifacts for mathematics teaching with the use of technology and their potential transformation if they had been applied in real educational settings. In the present study we took a constructionist perspective in order to investigate the distance between designed and actual implementation of activities with technological tools in the classroom of mathematics. More in particular, we considered scenarios and its accompanied material (i.e. microworlds, students' worksheets) as questionable, malleable and extensible objects rather than as static models that had simply to be strictly implemented by the teachers (Kynigos, 2007). Thus, we chose to develop our study around the creation and further modification of a scenario after its implementation in real classroom conditions. The multiplicity of our roles in this process (designers, facilitators of the teaching process, researchers) has necessitated the need to be engaged in collaborative activities around communities of inquiry (CoI) (Jaworski, 2003).

Teachers' CoIs can be an indispensable mechanism of support for the application of new, innovative actions, such as the use of technology in the teaching process. According to Jaworski (2003), the participants of a CoI related to mathematics classroom might be beginning, practicing, in-service teachers or even teacher educators. They -at all levels- are learners. Learning occurs while developing inquiring approaches on their practices (learning-on-practice) and rethinking about their actions and their artifacts. While starting wondering about issues of their teaching, by determining problems and complexities, they are approaching even more a situation of rethinking on action (reflection-on-action), during which they are able to take a thorough critical look over the facts (since they have already happened). This stage according to Jaworski (1998) constitutes an indication of meta-cognitive awareness. Simultaneously, this process provide the participants with the opportunity to enhance their knowledge, which includes –according to Shulman (1986)- the knowledge of mathematical content, the pedagogical one as well as the curricular knowledge. However, the theoretical knowledge that derives from the academic field is of different nature from the school-bound knowledge of the teachers (Jaworski, 2004). CoIs have come to normalize this difference, by enabling the implementation of theories and suggestions that are afterwards likely to become objects of reflection. In this context, the process of communally developing scenarios with the use of digital tools in mathematics, may contribute to the creation of a detailed, informal curriculum, enriched, well-documented with inquiry methods and has the potential to redefine the teacher-curriculum relationship. The specific community we refer to in the present paper had the purpose of operating as a link between members of the academic community, teachers and teacher educators.

The research

Context and aims: The current study is the outcome of the collaboration between a newly trained teacher educator for the pedagogical use of digital tools in the teaching of mathematics and two researchers from the academic field. At the beginning of the study the teacher educator had just completed the attendance of a 350-hour course at the University of Athens (i.e. in University Centres, UC) as part of a large scale professional development program of the Ministry of Education concerning teachers' familiarization with the use of digital technologies for teaching and learning of mathematics. The aim of the program was to provide the participants who were selected experienced mathematics teachers with methods, knowledge and experience in in-service teacher education and to educate them in the pedagogical uses of expressive digital media and communication technologies for the teaching and learning of mathematics. During their participation in the course the trainee teacher educators had developed a number of scenarios for different mathematics topics with the use of different categories of technological tools (e.g. DGS, Logo microworlds). However, the program at that time had not incorporated any process of implementation of the developed scenarios in real classroom setting. Consequently, the trainees had not had an opportunity to 'test' if and how their scenarios 'work' in real classroom conditions. In the present study we created a CoI as a means to address the transformations of didactical design through implementation of activities in mathematics classrooms. In this community, the teacher educator operated as secondary teacher since the designed tasks were implemented in some of her classes. A basic principle underlying this community was to create links between theory and practice by communal design of artifacts and further transformation of them after tested in real classrooms. In other words, we propose a cyclic process of developing artifacts for mathematics: successive phases of implementation inform further transformation of the previous versions of the artifacts. We started from the idea of approaching Thales Theorem with the use of Sketchpad for the 3rd grade of High-school through a relevant problematic situation. The introductory problem was:



On your screen you can see the bed of an irrigation channel. The length of the side AC is 10m. This side is graded throughout its length. When the cannel was full of water, a diver measured the height of the water level vertically and found it 9.50m.

If today the water level is in position K of the side AC that corresponds to the value 7.50m, what is the vertical height of the channels' water level? Should the person responsible for the channel send the diver again?

Figure 1. The introductory problem and the model of the Sketchpad microworld.

We created the corresponding material (worksheets and microworlds) and we tested them in two successive cycles of implementation (2 classes of 20 students, 4 two-hour lessons in each one of them). We were not that interested on the originality of the idea, but on the process of its implementation. We focused on the students' actions during the implementation of the activities. We discussed the findings that emerged during the lessons and we accordingly modified the current versions of the designed artifacts. By the end of this process we aimed at being able to fill in the seven units of a particular scenario structure that was developed by Educational Technology Lab: 1. Title, 2. Scenario's identity (writer, mathematics topic), 3. Rationale of the task (innovations, added value, teaching and learning problems related to a specific mathematical concept), 4. Context of implementation (grade, duration, location, prerequisite knowledge, necessary material and tools, social orchestration of the classroom, goals), 5. Analysis of activities / presentation of the implementation's phases (sequence of activities, roles of the participants, anticipated teaching and learning processes), 6. Extension of the scenario, 7. Bibliography. Our research focuses on the evolution of the modifications we did in the artifacts while gaining insight into their actual use in the classroom as well as from our evolving collaborative work.

Research questions: Through our study we aimed to investigate the following questions: How the designed artifacts were modified through their implementation in the classroom? Were there any unexpected incidents during the actual implementation that affected these modifications?

Research method: The present qualitative research deals with engineering a particular form of learning (teaching of Thales Theorem with the use of Sketchpad), and systematically studying this form of learning within the context defined by the means of supporting it. It has an interventionist nature, as well as prospective and reflective faces implemented through iterative design, thus it constitutes a design experiment (Cobb et al, 2003).

Data collection: a) Observation notes regarding all of the groups, the class as a whole, and every activity included in the worksheets, b) diary of what happened in every part, what impressed us, what could be done differently, c) videotaping of 4 groups of students' movements on the computer screen (CamStudio), d) worksheets completed by the students.

Data analysis: After each lesson and before the next one, a discussion between the members of the team followed. A comparison of the data acquired through the aforementioned means was conducted for every group of students. We then had to compare them with our goals and the anticipated ones. The conclusions of these discussions initially led to four categories of modifications: a) the worksheets b) the microworlds given to the students for investigation c) the teaching management. By the successive implementations, we further elaborated sub-categories of modifications within the above categories. In the results section of this paper we emphasize on these modifications rather than on the preceding interactions within the community members.

Results - Discussion

In the beginning all groups of students were given the first worksheet and a ready-made file with a Sketchpad microworld. The file consisted of 2 pages. On the first page, a ready model of the introductory problem was given. We decided that in this phase we were not interested in the process of modeling the problem by the students, as much as in their capability to explore it. On the 2nd page, a geometrical shape of Thales Theorem generalization through dynamic manipulation was given. Through a series of activities and with the use of Sketchpad tools (measurements, computing ratios, tabulation, dynamic manipulation of K – corresponding movement of the diver) the students were led to discovering the Thales Theorem and its implementations. The three kinds of modifications which emerged during the consecutive implementations in the laboratory will be described below.

1. Modifications to the worksheets

- 1a. *Integrating the model in the worksheet*: One of our main goals was the comprehension of the problem, thus, some of the straight line segments were given in the worksheet and the students were asked to fill in their given values or replace them with a variable, according to the data required. Simultaneously, a Sketchpad microworld which represented a model of the problem was given to the students. But it was noted that the students tended to use the measurements of the software, even in cases where we did not want them to. For instance, the students used these measurements for identifying the unknown segments of the problem, instead of representing them with a variable. The modification we did was the integration of the model in the worksheet, so that the students could focus only on the worksheet and thus having more possibilities to understand the problem at hand (i.e. to identify the variable and the constant quantities). This finding led us to recommend the use of the Sketchpad microworlds to take place later on. The recommendation was added in the 5th unit of the scenario structure.

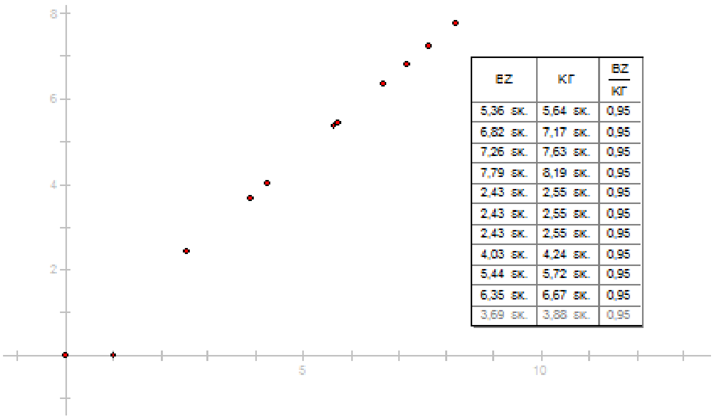
- *1b. Rewording the text:* In the cases where the students were not able to understand the text of the worksheet, we rephrased it through verbal modifications of the activities. Particularly, this happened only at the points where we judged that the text could have been formulated more clearly. Examples: i) Some questions were abstract, like "what happens when the water level changes?" The question had to be formulated more specifically, so that the students could focus on the variation of ratios, initially by moving K on AC. We additionally added a button to the Sketchpad file (in the form of animated graphics) for changing the water level when pressed. The simultaneous observation of the values of the ratio in every position of K offered a combination of representations which involved the dragging of K manually on AC and the animated graphics of the fluctuation of the water level with the update of the measurements. ii) After the students have experimented with the software and have discovered – formulated the Thales Theorem as well as the relation AK/KC=EB/BZ through the movement of K, they were asked to "give an explanation for this relation". What we had in mind was to engage students in identifying that this relation results by simply switching the means of Thales ratio. But no group of students understood what exactly we asked for. We thus rephrased the question as "how is this relation connected to the Thales Theorem?". iii) As mentioned earlier, in the 1st activity some straight line segments were given and the students were asked to fill in the requested data, in order to separate the known from the unknown ones and represent the latter with the help of variables. We determined though, that this was not understood by the students. So, we created a table with 2 columns (known/unknown segments) and asked the students to classify the given segments respectively and to either fill in their length or express them with the use of variables.

- *1c. Removing of "noisy" information from the activities*: In some cases, particular activities involved additional information. For instance, in order for the students to identify the equality of the ratios involved in the model (e.g. AK/EB=KC/BZ) 5 ratios, 2 products and 3 sums were given. The students had to measure and put them into a table. Then, through dynamic manipulation of K they were expected to observe the resulting measurements and distinguish the equal ratios.. But in practice, it appeared that this amount of information confused the students and disorientated them from the discovery of the requested relations. Part of this "noisy" information was withdrawn and this knowledge was taken into account when writing the 5th unit of our scenario.

- *1d. Integrating intermediary activities*: In cases where it was judged that there had to be a connection with previous knowledge (terms, concepts) and that connection had not been achieved with the existing activities or was not adequately taken into account in the planning, we added activities, either with further use of the software, or without it. Example: For the formulation of Thales Theorem, we had designed a set of activities. However, the students found it hard to characterize two segments as "proportional" or to use the word "proportionality" for the equality of two ratios. This difficulty was related to the fact that the students could not easily discern that the nominators of two equal ratios could belong to different lines. In order to support them overcome this difficulty, we added an activity which helped them relate the nominators with line AC and the denominators with line EZ. This experience was utilized in the 3rd unit of our scenario pertaining to the learning problems the students face with the particular mathematical concept.

- *1e. Performing visual modifications:* This type of modifications surprised us: In an activity where the students were asked to measure 6 segments, 5 of which were in a single line of the text and the 6th in the next one. We observed that the majority of students did not see and thus did not measure the 6th segment. We performed a visual modification in order for all the segments to be positioned in the same line of the text.

- *1f. Integrating new activities – Extending the scenario*: We left this type of modification for last, as the answers of 2 groups of students gave us the idea to extend the scenario to algebra and trigonometry. The students had already discovered Thales Theorem, its various forms and how could be used in the problem at hand. They had answered questions such as "compute the height of the water level when KC=6.5m" or "find the sidebar gradation when the height of the water level is 5m". Our next goal concerned the generalized form of Thales Theorem's use. Thus, we designed the following task: "The man responsible for maintaining the channel wants to know the height of the water level for every notch of the side AC. Find a relation that computes it". We expected them to transform the relation AC/EZ=KC/BZ as BZ=KC*EZ/AC. What gave us the idea of extending the activities to algebra and trigonometry was the answers of the two groups of students, who not only found the requested relation, but elaborated it further. Particularly, they replaced EZ/AC with the result of the measurements, which was 0.95, and so they express BZ as BZ=0.95*KC. Actually, they identified and expressed the linear dependence between the two segments. Having this stimulus from the students, we asked them insert the measures of BZ and KC in a table as well as the corresponding ratio. After taking nearly 10 measures of these segments for different positions of K, the students were asked to represent the corresponding pairs (KC, BZ) graphically. This way Thales Theorem was connected with the graph of proportional amounts (1rst grade of High-school). Finally, we added a 3rd page – microworld to the file (Figure 2).



EZ	KΓ	BZ/KΓ
5,36 εκ.	5,64 εκ.	0,95
6,82 εκ.	7,17 εκ.	0,95
7,26 εκ.	7,63 εκ.	0,95
7,79 εκ.	8,19 εκ.	0,95
2,43 εκ.	2,55 εκ.	0,95
2,43 εκ.	2,55 εκ.	0,95
2,43 εκ.	2,55 εκ.	0,95
4,03 εκ.	4,24 εκ.	0,95
5,44 εκ.	5,72 εκ.	0,95
6,35 εκ.	6,67 εκ.	0,95
3,69 εκ.	3,88 εκ.	0,95

Figure 2. Graphical and tabular representation of the proportional relation.

In addition, we modified the model of the 1rst page of the Sketchpad microworld, so that, by moving AC and EZ the students could detect that 0.95 is constant for the particular position of BZ, KC and if those are moved the value of their ratios changes. Finally, the slope of the straight line of the graph, led us to trigonometric numbers, which we utilized to prove the Thales Theorem in its general form for two random side lines.

2. Modifications to the given microworlds

- *2a. Inserting new buttons* as another possibility of multiple representations, mainly by inserting movement in the microworld (example 1bi above).

- *2b. Inserting pages*, in cases such as 1f that we described above.

- *2c. Reconstructing the geometrical representation of Thales Theorem*: The 2nd page of the Sketchpad file contained three different versions of Thales Theorem (intersection of the side lines within the zone defined by the three parallels, outside the zone or on one of them). We reconstructed the geometrical representation so as to provide students the opportunity to explore all versions of Thales Theorem in a single unified figure. Example: In an activity for the generalization of the Thales Theorem, in the case where the side lines intersect within the zone of parallels, we detected that it would be better if the side lines could be moved so that the students can discover the Thales Theory in all cases. Consequently, the microworld of the 2nd page was modified so that by dragging A or M on the first of the 3 parallels, the students can see all the possible versions of the Thales Theorem by observing the measurements.

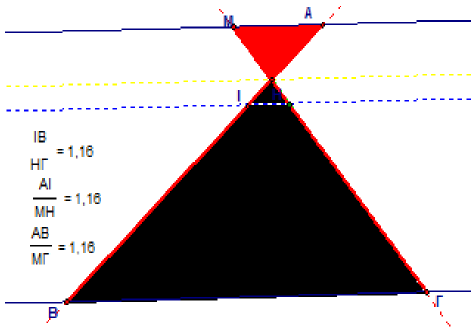


Figure 3. The final geometrical representation of Thales Theorem.

3. Modifications to the teaching management

Those modifications were incorporated in the scenario as concrete advice for the classroom management (the 5th unit of our scenario).

- *3a. Controlling the flow of the activity sequence in the classroom*: All groups of students were working with a high degree of autonomy. As the lesson progressed, we observed that the differences among the groups of the students in completing the activities of the worksheet were gradually growing. This of course means that the teacher has to provide more intensely support to the weaker groups and at the same time to organize frequently class discussions for sharing of ideas and approaches as well as institutionalization of the emergent knowledge.

- *3b. Integrating an intermediate lesson to the classroom*: We detected a need to elaborate further the knowledge gained in the laboratory in the traditional classroom (i.e. by solving exercises etc.).

Conclusions

Our general aim was to explore how constructionism as a design framework might contribute in addressing the potential of artifacts with technological tools in mathematics classrooms. We adopted a broadly constructionist framework in designing and modifying artifacts considering them as malleable objects transformed after reflection on the practices developed when implemented in real classroom settings. Three kinds of modifications emerged during the successive implementations of our designs in the classroom. These involved: modifications to the worksheets, to the given microworlds and to the teaching management. These modifications emerged as a result of incidents that took place during the implementation in the classroom. The most notable finding was the ease with which some students envisioned a geometrical relation in an algebraic way. This challenged the extension of our activities to involve linear functions and the notion of slope and thus making links between geometry, algebra and trigonometry. We also observed the ease with which the students used the measurements provided by the software which caused modifications leading to students to discern between measurement and computation. We detected difficulties that the students face in reading and comprehending the texts of the problems involved in the worksheets and developed ways to approach them (i.e. verbal and visual modifications to the worksheets). Management of the groups was also a case of special concern and we needed to revise our strategies several times. The functionalities of the microworlds that we provided to the students were realigned, as new cases we had not foreseen arose or the students gave us new ideas. The writing of the scenario was a result of this experience. The findings of our research show that this procedure enriched our knowledge (in Shulman's sense) and constituted a basis for developing a practically and theoretically documented scenario. It pinpointed features of the teaching and learning process whose inclusion in the scenario would be impossible if the practical implementation of the protoleia of our designs had not been preceded. Producing validated, well-documented material, in a pedagogical sense, has to be a main aim in training programs. This validation can occur through connecting training programs with teaching practice. Communities of inquiry can constitute the bridge for this connection and enrich academic knowledge with new research data which concern the implementation of digital technology. In summary, constructionist consideration of artifacts with digital tools as transformable objects in this study seemed to have created a context to forge connections between didactical design and classroom practice. This indicates also the productive nature of the challenge to situate constructionist approaches of design in a range of different contexts and computational environments in order to get an integrated framework to analyse the potential of artifacts with technological tools in mathematics classrooms.

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Construction kits for teachers: implications for design

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Abstract

This paper is about the ways constructionist software can shape and integrate design and the learning experiences. In particular, the experience of designing a constructionist kit is discussed and how it has been used to produce microworld instances. Based on the constructionist environment E-slate, a construction kit is produced relating geocoded components to historical facts. The kit, called Making Stories with Historical Facts (MaStoHF), presents synchronously spatial and temporal information together with other relevant information. It affords visualisation of historical facts of any kind, e.g. from creating art artefacts to local history, environmental innovations and scientific publications. The presentation of such information allows learners to visualise important events of a specific kind on a map and on a timeline not only realising its spatiotemporal dimensions but also accessing its context and learning to pose relevant questions. The paper identifies critical design decision parameters based on reflections from engaging teachers and pre-service teachers in the process of designing microworld instances.

Keywords

Constructionism in teacher education programs, Constructionist classroom experiences,

Introduction

When designing constructionist environments, it is of vital importance to provide learners with opportunities for examining their existing knowledge and structures that will enable them to reorganize their current models of thinking about the world and/or construct new models. It is also important for learners to develop competencies for communicating, exchanging, defending, proving, and justifying their ideas to the classroom. However, these types of tasks place a high cognitive demand on the learners.

Construction kits can provide useful tools for students to expand their understanding and make sense of new information. Students are given much more task management responsibility (Perkins, 1992) when they get engaged with construction kits, that is, prefabricated parts or processes they can use to 'build things' with. Interpretations of experience therefore become focal points and learners can elaborate and test those interpretations. Since learners are not expected to receive and store information, information banks become less central and are replaced by toolkits, sets of modular parts that students can use to generate new meanings and artifacts.

With constructionist kits, learners are empowered to take on more responsibility for task management than in conventional instruction. This shift of responsibility is necessary for students to become autonomous thinkers and learners. However, many students are not used to managing their own learning and so the teacher has to provide help and guidance to them in order to motivate and engage them in learning (Mulholland et al., 2012). Moreover, research in socio-constructionist perspectives and human and digital didactical support (Kynigos, 2007; Hoyles, Noss & Kent, 2004) suggests that working in groups can be of particular help to the students as opposed to individual learning experiences and supporting the whole classroom.

Essentially, a construction kit takes over some routine aspects of performing the task. It frees up processing resources that task performers can then use to perform the problem-solving aspects of the task (Norman, 1993). The most important considerations and theoretical notions have been incorporated in the construction kit, so that users do not have to deal with these issues themselves (Perkins, 1992). A construction kit should thus direct learners' attention to core aspects of the task and translate the routine aspects into prefabricated processes and parts. Furthermore, it should invite users to actually do things and not bother them with peripheral issues that can be dealt with later. Then, it provokes learning-by-doing and fosters inquiry based learning. For example, laying the facts on a map pinpoints to the geographical distribution of the scientific inventions or local environmental history, which could be elaborated further by queries expressing a personal standpoint.

A platform for designing construction kits

E-slate is an authoring environment which is not only based on the constructionist paradigm through building component configurations, but also on the connectivity metaphor, providing authors with multiple metaphors for connecting and thinking about component connections. E-slate projects are large – labor processes focusing on the idea of a custom desktop environment enabling users to hook up components and access their functionality in differing degrees.

Designing with the authoring environment E-slate follows a black and white box approach (Kynigos, 2004; 2007) in that it provides components as higher – order building blocks to construct software consisting of component configurations (black box). Components are black boxes in that the user cannot alter their main functionality and in that they are developed primarily to be technically efficient. These components are designed to be as generic as possible. On the other hand, it allows for specific components to be explored and manipulated, enabling inter-subjective exploration. Through the design of transparent (white-box) digital artifacts learners can construct and deconstruct objects and relations and have a deep structural access to the artifacts themselves (diSessa, 2000; Resnick et al, 2000). This white-box metaphor for construction and programming has generated a lot of creative thinking and involvement in learners mainly in informal educational settings.

The challenge is how this constructing – connecting combination can support creativity in building software. In designing construction kits, in particular, the challenge is where to draw the white box – black box line. This challenge, called 'principled deep structure access', involves decisions on where to draw the access line in favor of technical efficiency and higher – order functionality constructions. In essence it allows the designer to make decisions on what is important or not in the learning experience and to decide for the less important issues for the learner. The designer therefore breaks down into further constituent parts in order to gain higher order building blocks and learners can create interesting efficient software in a more focused way.

To address this challenge, a set of activities have been emerged that include:

- component architecture design and development, that is the generic E-slate environment
- software design and development of components

- secondary development of component configuration (authoring with E-slate)
- construction kits (e.g. MaStoHF)
- activity design and development (documented microworlds)
- collaboration with schools and school support
- teacher education
- research involving classroom and teacher seminar observation, tests and interviews

Focusing on the 3rd-5th set of activities, this paper discusses how secondary development of component configuration evolved to construction kits as well as activity design and development. In particular, the research team of ETL configured a set of components in order to relate geocoded data to historical facts. This configuration allowed the design of a construction kit that resulted in a number of instances of diverse educational content, e.g. history of art, place-based local history or scientific inventions. This configuration is considered a construction kit since it provides a set of components together with their connectors which teachers and learners can use to 'build things' with. They are also sets of modular parts that students can use to generate new meanings and artifacts. Some of these components can be omitted or extra can be added; new relationships can be created, each of these actions generates a new artefact (microworld) to play with.

Therefore, a new constructionist artifact is generated to be used by teachers and learners. For teachers to tailor the kit to their needs and those of their students, they should think of the theme of interest in new abstract ways that relate both to relevant information and the questions learners can pose. A critical issue here relates to the type of rules the kit affords: rules do not need to be logic-based but they can be value-labeled supporting reasoning beyond mathematical processes. Teachers, thus, not only need to collect information around a theme of interest but they should differentiate among rules of how this information can be used for meaning making. Learners, on the other hand, can visualize information in novel ways, generate questions and interpret answers that cultivate their reasoning, facilitate story-telling, and extend their understanding.

Why making stories with maps

Using space to structure problems, defining questions, finding answers, and expressing solutions (a skill called spatial thinking) requires a constructive combination of concepts of space, tools of representation, and processes of reasoning. By visualizing relationships within spatial structures, learners can perceive, remember, and analyze the static and dynamic properties of objects and the relationships between objects (Committee on the Support for the Thinking Spatially, Committee on Geography, 2005). Geospatial data can enable students and teachers to practice and apply spatial thinking in many areas of the curriculum and develop critical thinking skills that are central in science, the workplace, and everyday life (ibid). Therefore, spatial thinking plays a significant role in the information-based economy of the 21st-century.

Furthermore, geospatial understanding is developed greatly through narratives and there is a need to develop knowledge representation and reasoning techniques to help meaning and story making about a place – independent of its size (e.g. Europe or my neighbourhood). Creating stories out of geospatial data is rich in domain semantics and difficult for non-geography experts, like a primary teacher, to be expressed in formal language that a constructionist medium may require. Stories are usually expressed in everyday vocabulary with linguistic and cultural interpretations that need to be formalised into database descriptors, tables and queries. The research question therefore lies to the decisions that need to be made around the role of the technological tool in developing understanding, the elements to be discussed among learners and the activities to be designed by the teacher for the class.

Presenting the Construction kit

A construction kit called Making Stories with Historical Facts (MaStoHF) is being designed to address the need for developing spatial thinking skills as well as the ability to make stories out of a series of events. The construction kit consists of the following components and their connections:

- Map
- Timeline
- Database
- Other descriptive components, like photos, text, table etc.

These components allow the visualization of geocoded data, aiming to assist exploration and understanding. The visualization is specified both by temporal and spatial dimensions (Figure 1). The learner can zoom in and out of the timeline, choosing the period of interest, e.g. from 500 BC to 1700AC or from 1950-1975 AC or specific maps, e.g. Globe, Europe and Italy. Such visualization allows for exploring collocation and concurrency in the first instance.

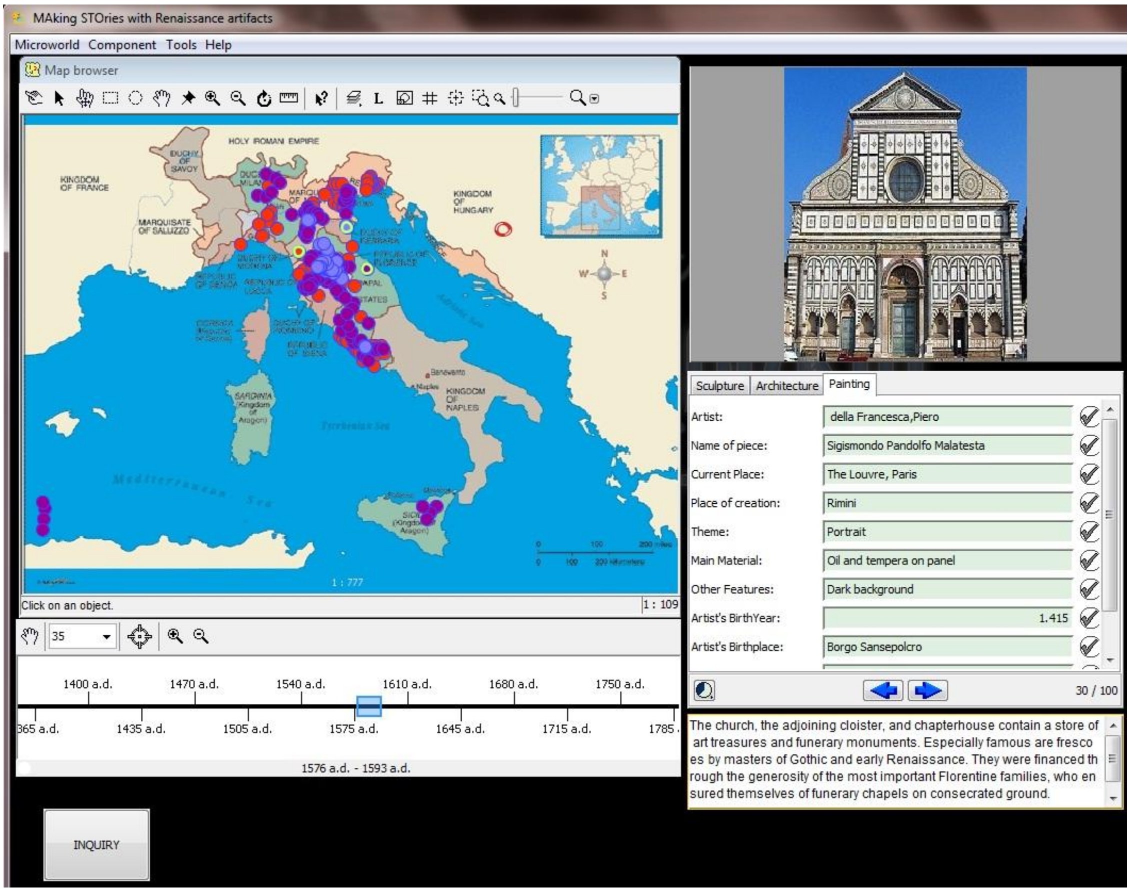

Figure 1: A screenshot of a MaStoHF instance relevant to Renaissance artefacts. This view shows the visualisation of geocoded data with temporal and other complimentary information.

Furthermore, MaStoHF allows the learner to explore the dataset based on queries with logical operators (Figure 2). With such queries the learner can question, express and test hypotheses, allowing for rapid inquiries either planned by the teacher or spontaneously occurred by learners. Such queries provide learners with a powerful tool of dataset exploration that facilitate the ability to ask relevant questions and engage in problem solving processes.

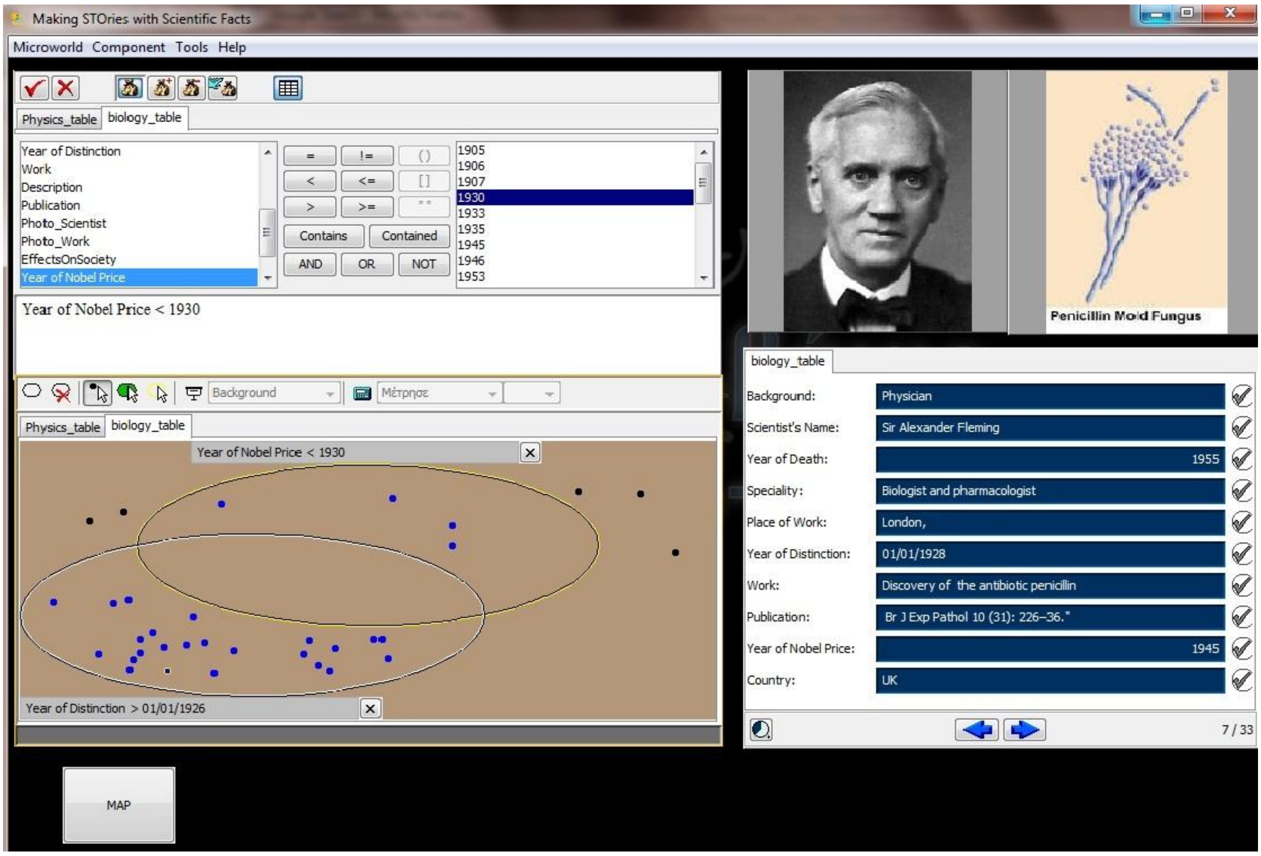

Figure 2: A screenshot of a MaStoHF instance related to Scientific Innovative Facts. This view shows how inquiries can be carried out by learners.

Designing with MaStoHF

Our aim was to explore how such a construction kit would enable teachers and prospective teachers in developing curricula based on active explorations of geocoded datasets. Having developed a template where the basic components are already available, the teacher needed to tailor the template to their particular curriculum needs. Three in-service teachers devoted time and effort as part of their postgraduate training. Based on our experience of supporting those teachers, we identified critical design decision parameters that influence the process of designing MaStoHF microworld instances (Table 1).

These parameters are closely related and they are going through iterative phases. For example, fields may specify how the facts will be told but at a later phase, and facts may notate which fields need to emerge. Below, we analyze each parameter by relating MaStoHF design decisions to questions related to scenario design.

Designing the database

A fact is an entity that is represented by information in a database. Depending on the specific context, a fact may be specified through text, images, audio, mind maps or videos.

All facts are gathered in a database directly associated to the map. The database should contain information relevant to the fact that is chosen to be of significance. Therefore specifying the database fields is of paramount importance. Fields specify the information that adequately describes a fact. They categorize the semantic information and specify the type of queries the learner will be able to ask at a later phase. Therefore an important question that the teacher-designer should address is 'What elements (descriptors) of the story are important?'.

Design parameters	Related questions
Designing the database	What elements of the story are important?
Choosing the fact	What is the main element that the story will be based on?
Specifying the story	What parts of the story should be stressed through the system? What parts of the story is to be discussed in class? What parts of the story are to be explored by the learners?
Setting and testing hypothesis (Inquiring)	

Table 1: The main design parameters

Choosing the fact

The collection of facts specifies the wealth of the dataset. When choosing the way to describe a fact, the teacher designer should focus on the unique element around which the story will evolve. For the history of Science, for example, the fact can be the innovation that was awarded with a Nobel price. This unique element and its characteristics influence the fields of the database within an iterative process where the story descriptors denote the unique fact and then the fact specifies the descriptors.

When deciding on the unique element of the story, the teacher-designer decides on the perspective of the story as well as the significance of some events against some others. For the place-based local history scenario, for example, the fact could be for example the erection of specific buildings in a civic environment (Anastopoulou et al., 2012). Such a fact focuses on particular uses and the effect of citizens' related social needs not only on the image of the city but also on its overall function, ecological balance, and perceived quality of life. Such a decision denotes that facts around changes in the landscape or disturbances of the flora and fauna become less relevant. Therefore an important question that the teacher-designer should address is: 'What is the main element that the story will be based on?'

Specifying the story

The narrative construction starts from the decisions of teacher-designer but with MaStoHF, it is going to be extended or further specified by the students. In particular, the teacher-designer can decide on the following questions that also specify the degree of students' freedom.

- What parts of the story should be stressed through the system?
- What parts of the story is to be discussed in class?

- What parts of the story are to be explored by the learners?

Setting and testing hypothesis (Inquiring)

The narrative construction is further developed when learners enter a query into the system. Queries are formal statements of information needs, in order for example to find which facts are collocated or happening concurrently. For the query to make sense, it should not identify only a single object in the collection. Instead, several objects may match the query, perhaps with different degrees of relevancy. Queries are matched against the database information so that learners can explore elements of the dataset. The matching facts are presented as dots in different colors. Learners can identify which fact refers to the dot by clicking on it- pre-defined information is made available to inform them.

Learners can structure the similarities and differences between concrete concepts through a Venn diagram. A Venn Diagram is a visual organizer used to compare and contrast concrete concepts. Venn Diagrams are made up of two or more overlapping circles that sometimes interlap. One circle is for comparing, the other circle is for contrasting and the overlap is for the similarities. Learners can inquire around descriptors of each fact, visualizing similarities, differences and other comparisons. For example, in a scenario around scientific facts, learners could run queries around the time elapsed between publishing scientific innovations and receiving the Nobel price (Figure 2).

Critical questions for the teacher-designer refer to the activities that would facilitate students to try out meaningful comparisons that would engage them in fruitful interactions and debates with their peers.

Conclusions

For learners to be responsible for communicating their ideas to the classroom, they need to create and respond to opportunities to make sense of the information at hand. Construction kits can empower learners to take on more responsibility for task management by directing their attention to core aspects of the task and translate the routine aspects into prefabricated processes and parts. In designing construction kits, however, the challenge is where to draw the white box – black box line, in other words, for the teacher-designer to make decisions on what is important or not in the learning experience and to decide for the less important issues for the learner.

This paper discussed how secondary development of component configuration of a constructionist platform evolved to construction kits as well as activity design and development. By designing MaStoHF, a set of components were configured in order to relate geocoded data to facts with a temporal dimension. In essence, it related spatial thinking skills to narrative construction based on geo-temporal data. It challenged teacher-designers to think of stories usually expressed in everyday vocabulary but formalise them into database descriptors, tables and queries. This challenge led to design decisions on their behalf around the role of the technological tool in developing understanding, the elements to be discussed among learners and the activities to be designed by the teacher for the class.

Based on the experience gained from supporting in-service teachers develop MaStoHF instances of diverse educational content, we proposed a set of design decision parameters. These parameters are in particular: designing the database, choosing the fact, specifying the story, setting and testing a hypothesis. These design decision parameters relate directly to questions for the teacher-designer around the ways to facilitate and engage students in fruitful interactions and debates with their peers.

In the future, we are interested in finding out how students in real settings engage in active explorations of geo-temporal datasets based on the curricula that their teachers developed. We envisage that visualizations that allow exploration of collocation and concurrency as well as setting and testing hypothesis, provide learners with a powerful tool of dataset exploration that facilitate the ability to ask relevant questions and problem solving.

Acknowledgements

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Educational online social networking in tertiary education - A teaching intervention

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Abstract

This paper presents a descriptive study concerning the use of an educational online social network in the framework of a teaching intervention in tertiary education. The basic tool used was the network "Logo in Education: a community of practice and learning" (http://logogreekworld.ning.com), as well as data from the network members' interaction with the network tools.

In this paper, we describe the basic characteristics of the teaching intervention and present the results of an experimental study evaluating it, indicating, at the same time, the students' skills, attitudes and views concerning the use of Logo and of the network tools before and after their participation in the network. Finally, we discuss key subjects and pose open questions for future exploration.

Keywords

Social networking, educational social network, Logo

Introduction

The use of online social networking services in education is constantly gaining ground at a global level and has become a particularly popular trend. Modern research focuses on the exponential development of social networking sites as well as on the increasing exploitation of social networking in the teaching and learning process (National School Boards Association, 2007; Office of Communications, 2008; Yuen & Yuen, 2008; Karabulut et al, 2009).

According to Steve Hargadon (2009a), Web 2.0 is going to dramatically change the 21st century landscape in education, shaping the way in which students approach learning, educators approach teaching and, more and more, the way in which teachers interact with, and learn from each other.

Hargadon (2009b) defines "Social Networking" as "the Aggregation of Web Tools for Building Community & Content". Also he advocates (Hargadon, 2009c): ""Educational Networking" is the use of social networking technologies for educational purposes. Because the phrase "social networking" can carry some negative connotations for educators, the phrase "educational networking" may be a way of more objectively discussing the pedagogical value of these tools."

An educational online social network (EOSN) is a network where members of the educational community, like teachers, students, parents, school advisors and so on may register, communicate, interact and exchange educational information, ideas, views and material focusing on various specialized subjects and concerns (Glezou et. al., 2010).

Educational online social networks may contribute to the upgrading of the educational system, the teaching-learning process and lifelong learning. The members of the teaching community may benefit from this new social networking via Internet trend in a personal as well as collective level. Educational online social networks may function as Digital Learning Communities. Thus, the exploration of social networking in the teaching process is a really important issue.

The present paper focuses on a descriptive study concerning the use of an educational online social network in the framework of a teaching intervention in tertiary education. The basic tool used was the network “Logo in Education: A Learning Community of Practice” (“LogoinEdu” as abbreviation).

The paper aims to study and evaluate the teaching intervention that took place in the frame of the course “Didactics of Informatics”, Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens, during the winter semester 2009 – 2010. The study objectives include: a) the presentation of students’ skills, attitudes and views concerning the use of Logo and the network tools before and after their participation in the network and b) the exploration of the interaction developed between the students by use of the network tools.

The paper presents the basic characteristics of the teaching intervention, points out the results of the evaluation study, discusses some key subjects and poses open questions for future work.

Description of the “Logo in Education: A Learning Community of Practice” EOSN

The educational online social network “Logo in Education: A Learning Community of Practice” (“LogoinEdu” as abbreviation) was created by a teacher of Physics/Informatics at the end of May 2009 as an independent initiative using Ning platform (Fig. 1). Its goal is the communication, cooperation and exchange of views, ideas and material between members of the educational community from different fields, age and background, who are interested in exploiting Logo as a programming language and philosophy in education. This EOSN primarily concerns teachers of Informatics and Computer Science and in parallel, teachers of various specialties, cognitive subjects and all educational levels who are interested in or/and experimenting with the usage of Logo programming language in the teaching praxis.

Figure 1. Snapshot of home page of the “LogoinEdu” EOSN

As it is denoted in the “LogoinEdu” subtitle “Learn - Construct - Collaborate - Communicate” the ulterior objective of "LogoinEdu" is to function as a learning community of practice, as a forum for the dialogue and mutual support between members of the educational community focusing on the pedagogical exploitation of Logo and Logo-like environments attempting to improve the teaching-learning process.

The network members are invited to interact in the spirit of Social Constructionism: "Let's function as a community of practice and learning and exchange views, experiences, practices and tools, such as microworlds, websites, lesson plans, worksheets, codes and all kinds of resources necessary for our teaching practice, with the purpose to upgrade the teaching-learning process." as it is characteristically mentioned in the network pages.

The groups' subjects cover every level of education and extend beyond the field of Logo. Most of the groups are active and share many discussions, comments and rich educational material about learning/ familiarizing with/ delving into the various Logo-like environments. On March 25th 2012, "LogoinEdu" counted 844 members and 34 groups.

Presentation of the teaching intervention

On November 5th 2009, the group "Didactics of Informatics" was added to the network in a first attempt to explore the possibility of exploiting social networking in the teaching process. As opposed to the other groups of the network, this group was chosen to have controlled registration and access, i.e. to be open only to students and teachers of the "Didactics of Informatics" course (Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens) during the winter semester 2009 – 2010. Only the registered members of the group have access to the group discussions and the ability to add new discussions, comments and post material.

The students came for the first time in contact with the network on 5/11/2010 in the framework of a 3-hour seminar (oral presentation, not workshop) titled "Introduction to Logo". The seminar involved an introduction to know Logo as a programming language and educational philosophy, focusing on the teaching use of Logo and the presentation of Logo-like environments, and especially MicroWorlds Pro. During the seminar, the network was presented through a direct connection to the web and through browsing its basic pages that lasted about 15 minutes. The students were invited to register to the network by providing their student e-mail address so as for their participation request to be confirmed and accepted.

The activity was titled "Assessment of the participation experience to the online educational social network "Logo in Education: a community of practice and learning". According to the activity's announcement: "This activity has to do with your participation to the group "Didactics of Informatics" of the "Logo in Education: a community of practice and learning" network. You are asked to register to the educational social network "Logo in Education: a community of practice and learning", and in particular to the network group "Didactics of Informatics". You can browse the network freely, search for/study various materials and participate actively to the groups and the network's other activities. The activity will be considered complete with the posting of a comment to the discussion board "Working out the activity – Assessment of the participation experience to the network" as a recording of your personal experience of participation to the network. In your personal comment (free text of about 50-200 words) you can e.g. mention if this is the first time you participate in an educational social network, what were your benefits from that, what problems toy faced, or characterize your experience as positive/negative, constructive/useless, interesting/ indifferent. All views, judgements and suggestions are respectable and acceptable. This activity is individual and will be graded by one point in the framework of the course "Didactics of Informatics". The deadline for the submission of comments is: 6/12/09. For any questions or queries you can communicate with the activity supervisor". In the group discussion "Activity evaluation" a questionnaire was posted as a tool for the evaluation of the activity. Students were asked to fill in the questionnaire voluntarily in order to contribute to the feedback process and post their personal comment to the relevant discussion.

Experimental evaluation study

An experimental evaluation study of the teaching intervention was carried out in order to explore the students' views about the use of social networking tools and assess the effectiveness of the application. The study was directed by two main exploratory questions: a) What is the students' general opinion about the application of the activity? and b) What are the important issues as far as the use of an educational network in the teaching process is concerned?

A multi-method approach was adopted for the exploration of the students' opinions. This included the collection of data by use of qualitative and quantitative exploratory techniques, such as observation notes, student comments, student network activity data and, finally, the questionnaire.

The questionnaire consisted of four parts. The first part was designed to collect demographic and personal data from the students. The second part had to do with the students' previous experience before the activity and included 5 questions-criteria. The third part was about the experience gained after the activity and included: a) 10 questions-criteria about Logo and b) 15 questions-criteria about the network, aiming to evaluate the activity application success. The answer to each of the criteria was based on a likert-type scale ranging from 1 (Not at all) to 5 (Very much). The fourth part of the questionnaire included 4 closed-type questions (yes-no) and 7 open-type rethinking questions in order to collect comments, views and suggestions from the students.

The analysis of data collected from the observation notes, the student comments, the student network activity data and the open questions of the questionnaire was carried out with the help of a content analysis method. The qualitative analysis of the data was based on the recording of all data and their study by the researcher.

201 members of the group "Didactics of Informatics" participated in the study (2 Ts and 199 Ss, where T: teacher (T1 and T2) and S: student). One hundred and eighty two students (138 men-76% and 44 women-24%) voluntarily filled in and returned the questionnaire, which was created according to the needs of the evaluation study.

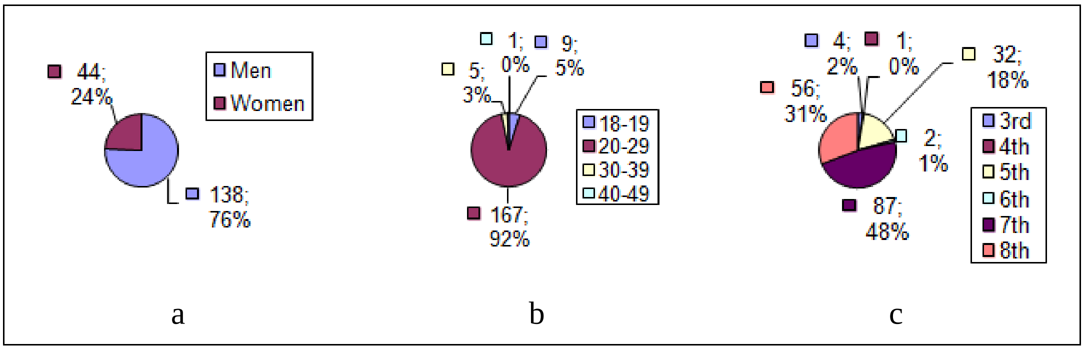

Figure 2. Student distribution based on a) sex, b) age, c) semester of studies

As it turned out, the overwhelming majority of the students (91%) belonged to the age group of

20-29 years, 3% to the age group of 30-39 years, 1% to the group over 40, while 5% was aged between 18-19 years, as shown in Figure 2.

Data analysis -Results

From the data analysis, we can point out the following:

The student registration and participation to the network begun from the first day of the activity and increased daily. The majority of the students did not register to the group at once. As a result, their participation to the network was limited before the posting of the last comment. During the last five days before the deadline of the activity, the number of registrations amounted to 109 (54,8% of the total registrations number).

On the group's comment board 5 comments were recorded (1 from S, 4 from T1).

The majority of the students showed some hesitation to post a question to the discussion groups and resorted to sending an email to the activity supervisor. The activity supervisor sent a total of 87 email messages (mostly clarifying answers to questions about the activity, or to queries) to students and received 45 messages via the network mail service and 24 via other e-mail services outside the network. Two students were kindly asked to change their profile pictures because they were considered provocative for an educational network. Both students complied with the recommendation. Table 1 presents characteristic data from the group discussions. The groups are presented in ascending order, based on the date of their creation.

Discussion subjects	Member title	Date of creation	Last activities	Number of answers
Carrying out the activity – Assessment of the network participation experience	T1	5/11/09	6/12/2009	254
Questions about Logo and MicroWorlds Pro	T1	5/11/09	5/11/2009	0
Introductive course to Logo (under construction) in the moodle platform	T1	5/11/09	5/11/2009	0
Using online social networking in the teaching process	T1	6/11/09	3/12/2009	5
Questions about the network	T1	10/11/09	10/11/2009	0
Questions, suggestions and views about the carrying out of the activity	T1	16/11/09	4/12/2009	10
Our criteria for the network evaluation	S	25/11/09	26/11/2009	2
Activity evaluation	T1	30/11/09	6/12/2009	1
Total				*272*

Table 1. Presentation of the group discussion data

The activity supervisor took part in spontaneous online chat discussions with students thirty two times, mostly in the last days before the deadline for posting the comment. During the chat discussions, there was an increased motivation of the students who registered to the network with a delay (Figure 3). As a whole, 58 students took part in a chat discussion with the presence of the supervisor.

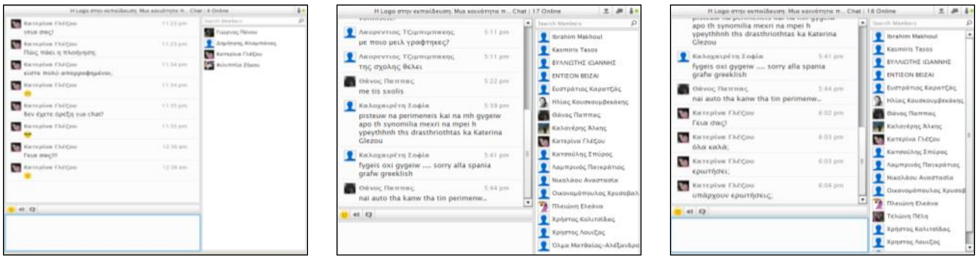

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Figure 3. Use of the chat: a) 24/11/09 - 12:38 am, b) 06/12/09 - 5:45 pm, c) 06/12/09 - 6:05 pm

From the 199 students that registered to the group, seventeen did not deliver the questionnaire, while five students didn't post a comment at all. Sixteen students registered to other network groups as well. Twenty six students updated their profile. Forty nine students added a profile picture, 28 of which chose a personal photo, while 21 chose another picture/image. Fifty eight students participated in other discussions besides the ones of their group. Eleven students participated in 2 network groups, four students in 3 groups, one in four groups and two students in five groups. The authorization for the participation to the group was an issue of delay that caused discomfort to 12 students who initially registered to the network with a different e-mail address than their student e-mail address, so their application of participation to the group did not get accepted. The rejection of their registration application was accompanied by an email that urged them to apply again by using their student email address. The time between the registration application to the group and its acceptance or rejection ranged between 8 minutes and 26 hours with an average time of 2 hours and 14 minutes.

The questionnaire results are presented in reference to: a) previous experience shown in Figure 4, b) the experience gained concerning: i) Logo in Figure 5, ii) the network in Figure 6 and iii) the overall experience assessment in Figure 7.

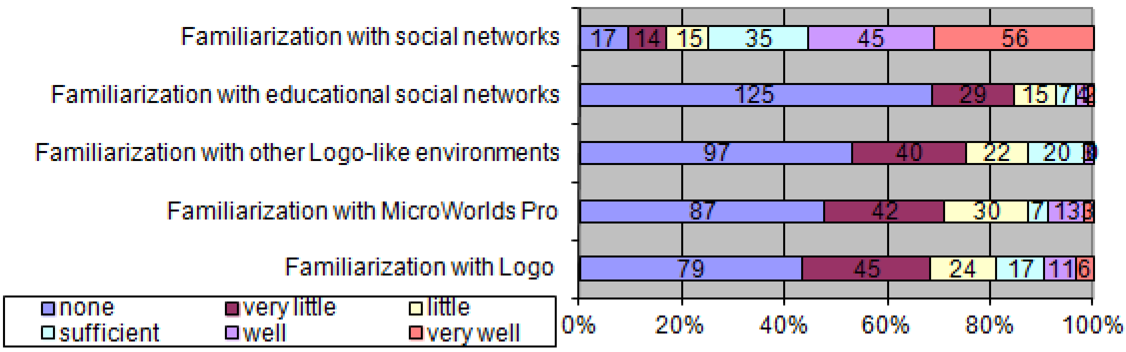

Figure 4. Questionnaire results in reference to previous experience

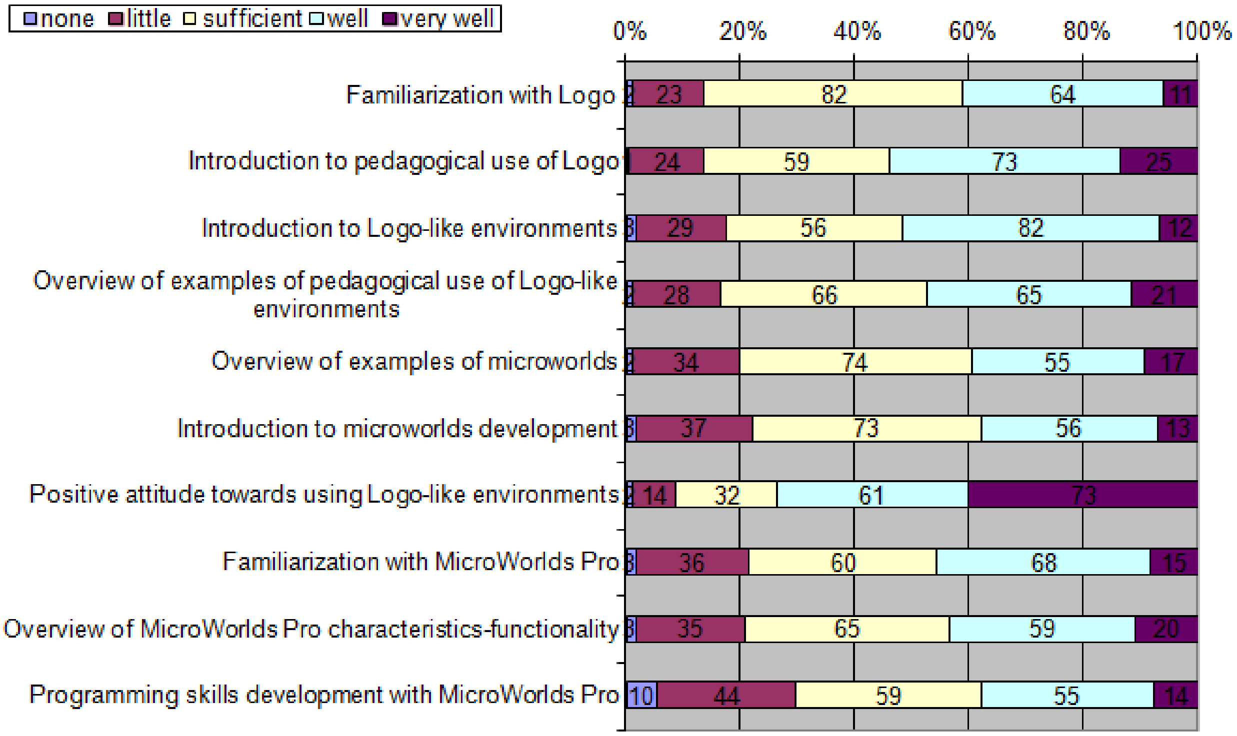

Figure 5. Questionnaire results in reference to the experience gained concerning Logo

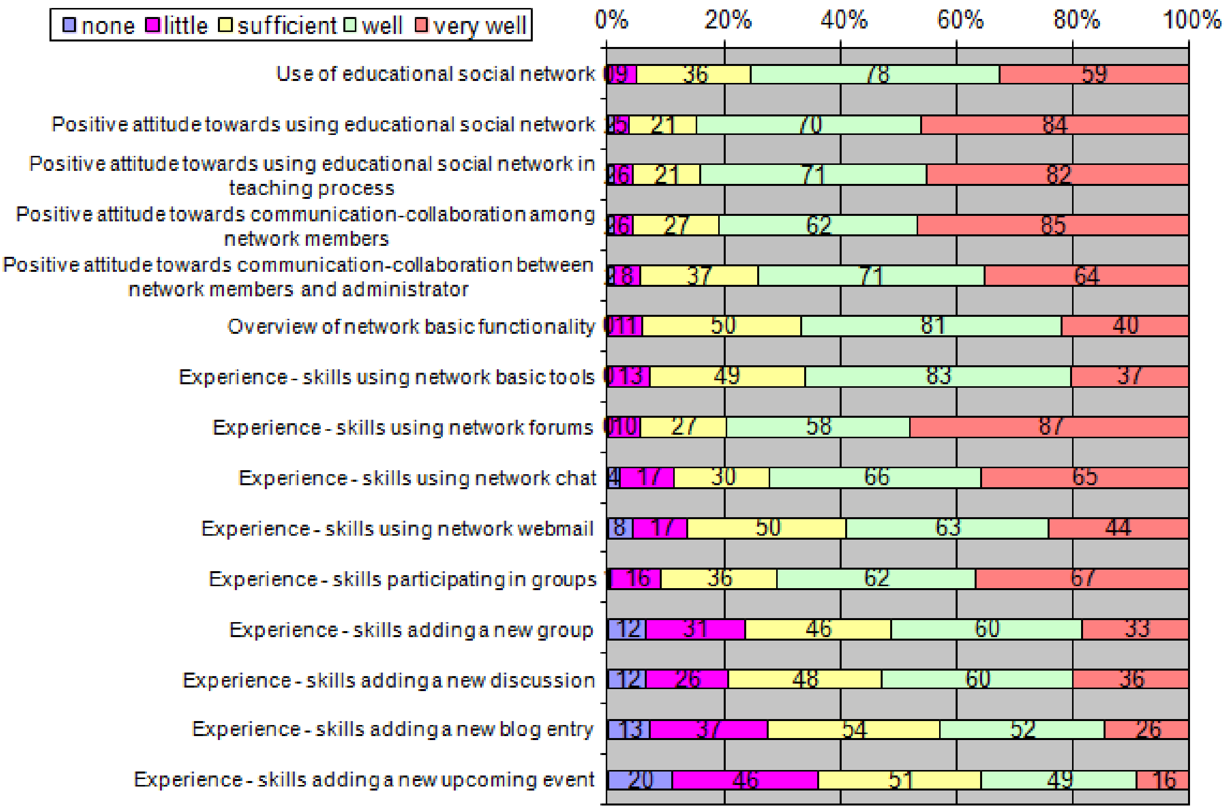

Figure 6. Questionnaire results in reference to the experience gained concerning the network

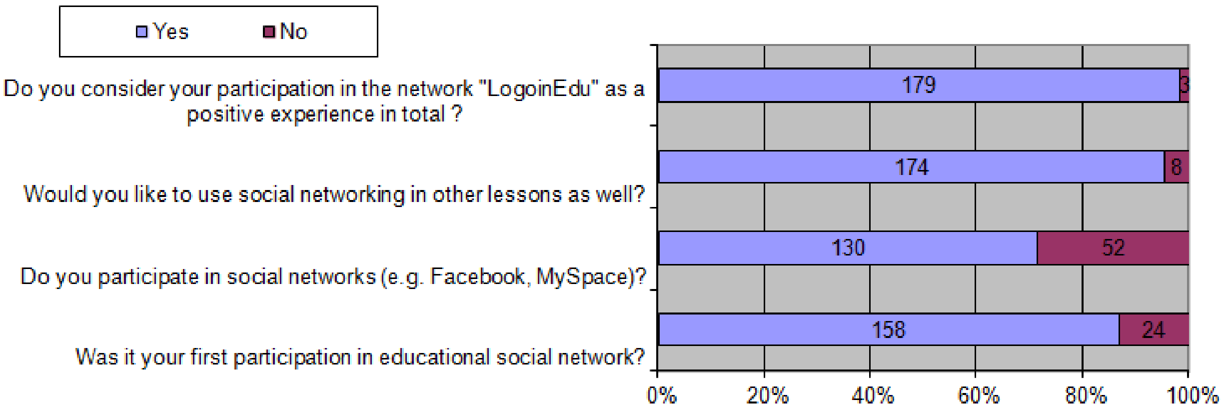

Figure 7. Questionnaire results in reference to the overall experience assessment

These results indicate that the students -as they declared themselves- developed the basic technique and pedagogical knowledge in a satisfactory level as far as the use of Logo, of Logo-like environments (especially MicroWorlds), were concerned and familiarized to a certain extent with the social networking tools provided. From the 182 students that took part in the research, only sixty three answered the open type questions of the questionnaire. The results indicate that students were satisfied with their participation in the activity. There were also some students who liked participating in the network and characterized the intervention as an “unprecedented”, “really innovative”, “radical”, “very useful” experience. Many students expressed openly their desire for the adoption of similar intervention concerning social networking in other courses as well. Many students pointed out that their participation to the network surprised them, since they discovered that there are indeed teachers that “love programming”, “work hard to become better teachers”, “believe in the value of Logo”.

Conclusions – Discussion

This paper aims to contribute to the dialogue concerning the possibility of using an educational online social network in the teaching process.

In the framework of the paper, we present the main characteristics of a teaching intervention in tertiary education and report the results of the experimental evaluation study. The skills, attitudes and views of the students –the potential future Informatics teachers- are pointed out as far as the use of Logo and the network tools are concerned before and after their participation in the network. As a whole, the teaching intervention was evaluated positively by the majority of all parts involved. According to the evaluation study results, the students regarded that they developed the basic technique and pedagogical knowledge concerning the use of Logo and Logo-like environments to a satisfactory level, and familiarized to a certain extent with the social networking tools provided. The students, in their majority, participated for the first time to an educational network and recognized the significance and the added value of using educational social networking. The degree of the students’ participation and interaction to the network was estimated rather lower than expected, given that they were students of the Informatics Department and, thus, were expected to be highly familiarized with Web 2.0 tools.

An important open educational issue is the study of teacher ideas and attitudes towards the integration of social networking in everyday teaching process. The exploitation of social networking in practice requires, apart from contemporary Internet platforms and appropriate educational tools, some proper teaching and training interventions on the part of educators, so as the trainees to meet the needs of their new didactic-learning roles, such as the increased necessity for teamwork. How to implement this novel paradigm and how effective its introduction into teaching-learning process is still to be investigated.

The educational online social network “Logo in Education: A Learning Community of Practice” may offer a promising new way to recruit participants, particularly students and teachers, into Logo research. The teaching intervention need to be further evaluated, regarding its effect on scaffolding Logo programming -programming language and philosophy- and gradual familiarization with the Logo-like programming environments. Further research is needed to help in identifying the key aspects around how such teaching approaches are used to the best effect for students’ engagement and learning. In addition, more research is needed for the identification of the special design characteristics of the learning activities, which promote engagement, artifact and knowledge construction, “thinking about thinking”, meaning negotiation and collaboration for different learners.

Future Work

The design of effective and constructive teaching interventions concerning the use of educational social networking in order to better support student engagement in Logo programming skills development remains an open issue. Our future research plans focus on exploring the implementation of different teaching interventions which might lead to the most effective combinations to support members’ engagement and learning. Some crucial questions remain unanswered: a) How can we facilitate the network members in order to function as active Digital Learning Community members? b) Which are the tools that can best support communication, interaction and cooperation between the members? c) How can the network administrator promote communication and cooperation between the members? d) Which tools can better contribute to personal development and learning?

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Social Interactions Among Modelers

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Abstract

NetLogo (Wilensky, 1999) is an agent-based modeling language that has successfully been used in a variety of constructionist contexts. However, NetLogo lacks built-in support for making artifacts public, or for creating models collaboratively. Our research project, the "Modeling Commons," is designed to make NetLogo not only an effective tool for creating models, but also for sharing them with others and collaborating during the modeling process. In this study, we interviewed NetLogo modelers about their interactions —sharing, cooperation, and collaboration — with others during the modeling process. We found examples of all three interactions, but also saw that modelers collaborate separately, and differently, with both programmers and domain experts. In this paper, we describe these interactions, including the distinction between "code collaboration" and "domain collaboration." We describe changes we intend to make to the Modeling Commons to provide domain experts with additional affordances for collaboration.

Keywords

Constructionism, Collaboration, Modeling, Social interactions, CSCL, World Wide Web

Introduction

Constructionism (Papert, 1980) argues in favor of learning through the creation and sharing of artifacts. NetLogo (Wilensky, 1999) is an agent-based modeling environment that has long supported individual constructionist learning (Jonassen, 2006; Reisman & Wilensky, 2006).

The artifacts created by NetLogo users are models — software simulations, typically in the domains of science, mathematics, and social sciences. Models have long been used by scientists and engineers, in a wide variety of domains, and for many different reasons (Morrison & Morgan, 1999; Epstein, 2008). Software simulations can be used for understanding, exploration, and prediction to test plausible explanations for phenomena, discover new relationships from multiple runs of models at different settings, and predict future events based on past trends and complex systems principles.

NetLogo has many thousands of users, ranging from middle- and high-school students learning about science, modelling, and complexity, through university and corporate researchers. However, NetLogo lacks built-in support for sharing models, let alone interacting during the modeling process. Recent theory and evidence demonstrate the central role that social interaction plays in learning (Vygotsky, 1978; Lave & Wenger, 1991; Wenger, 1998) in general, and when modeling in particular (Bollen, Hoppe, Milrad, & Pinkwart, 2002; de Aennle, 2009). Moreover, Papert's original description of constructionism (Papert, 1980) describes not only building, but also sharing with others, as a critical part of the process.

For example, among software developers, "pair programming" (Beck, 2000) has become a popular method for collaboration, one which may be appropriate for at least some NetLogo modelers. Studies indicate that pair programming results in higher-quality software, but also in a feeling among developers that they have learned much from one another (Cockburn & Williams, 2001).

In this study, we are interested in the social interactions that take place among modelers in order to better design a supporting platform we have created, the Modeling Commons. In this paper, we focus on three forms of interaction: *collaboration*, *cooperation*, and *sharing*.

Researchers distinguish between collaboration and cooperation when discussing interactions: "In cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output. In collaboration, partners do the work 'together' " (Dillenbourg, 1999). In a collaborative project, no participant can continue on his or her task without input, advice, and assistance from one or more partners, what has been called "genuine interdependence" (Salomon, 1992). By contrast, cooperation describes a situation in which the main task is split into parallel, somewhat independent sub-tasks. We see sharing — i.e., showing an artifact to others after the creation process, rather than while it is taking place — as a third type of personal interaction. In designing the Modeling Commons, we wished to support all three of these forms of interaction.

Our research project, the Modeling Commons (Lerner, Levy, & Wilensky, 2010b), is a Web platform for social modeling, both facilitating interactions among modelers and providing insights into modelers' interactions and learning. Using a Web browser, members of the Modeling Commons can share, discuss, categorize, and collaboratively author NetLogo models. As a design-research project (Brown, 1992; Collins, 1992), insights gained from user experiences are used to change and improve the Modeling Commons software, to better encourage improved interactions — and, we hope, improved models, as well.

The Modeling Commons was formally announced to the NetLogo community in January 2012. As of April, more than 70 new users have registered for the Modeling Commons. Preliminary versions were used by university courses on constructionism, modeling, and complexity, as well as by individual researchers and modelers. Feedback from these initial trials, as well as analysis of the system's logs (Lerner, Levy, & Wilensky, 2010a), helped us to improve the system, as well as to understand unique and various ways in which the Modeling Commons may be used.

NetLogo modelers have been interacting for years without the benefit of the Modeling Commons. To be effective, our design research must incorporate existing practices among NetLogo modelers, without the Modeling Commons. However, our ultimate goal is not just to facilitate existing interactions, but to allow for the creation and development of new paradigms, such that interacting via the Modeling Commons will be more effective than even face-to-face collaboration could be (Hollan & Stornetta, 1992).

This paper describes a study that we conducted in order to better understand how NetLogo users currently interact, without benefit of the Modeling Commons. The research question for this study was: What types of interactions and organizational structures currently exist among NetLogo users, without the Modeling Commons? Answering this question will not only help us to understand current practice, but also how we can detect and categorize interactions among users of the Modeling Commons.

Methods

Even before the study began, we had strong anecdotal evidence – from our interactions with NetLogo users, including many students learning NetLogo as part of a university class – that the question was not whether there were social interactions among modelers, but rather what form they took, and how the modeling process was affected as a result.

Participants: We aimed to recruit up to 20 people, experienced with NetLogo but unfamiliar with the Modeling Commons, to describe the ways in which they develop models, and the interactions they have when doing so. Our main source for subjects was NetLogo-users, a public e-mail list that with nearly 4,000 users that has served for more than a decade as the chief method for peer-to-peer communication and support within the NetLogo community. Via private e-mail, we asked approximately 15 of the most active recent participants in NetLogo-users to participate in our study. Following that invitation, we asked for volunteers among all members of NetLogo-users to agree to participate in our study. Additional subjects were recruited via the snowball method, as well as by initiating contact with specific people whom we knew to be active in the NetLogo community. We recognize that there was some selection bias, in that we specifically indicated in our recruitment messages that we would be asking about collaboration and personal interactions. Our subjects may well have been more likely to collaborate with others than the average NetLogo user.

These efforts resulted in nine interviews with 10 different subjects. (One interview was with a pair of subjects who often work together.) All were adult researchers, and nearly all either had a PhD or were working toward one. Only one had used the Modeling Commons before the interview took place, but all were experienced NetLogo users, with several of them having worked with NetLogo for several years, on a number of significant models.

Research tools and paradigm: Interviews were conducted by telephone or Skype in the clinical style (Ginsburg, 1997). Interviews were recorded, transcribed, and coded for topics having to do with social interactions and modeling.

Results

Interview subjects were all asked whether they worked with others when creating NetLogo models. The answer was uniformly positive, with all saying that they work with others at some point during the modeling process. However, the subjects reported engaging in widely divergent types of interactions with others, including all three types mentioned above: Sharing, cooperation, and collaboration.

Sharing: All of the subjects reported that they have shared NetLogo models — that is, shown a model to others after having reached at least one significant milestone. Most reported having shared models with a small number of people, such as a doctoral committee. One subject reported having shared his model with the readers of a journal article he wrote; when asked how he shared the model, he said that he had used the Modeling Commons to do so.

In some cases, subjects said that they used NetLogo's "applet" feature to share a model via a Web site, allowing others to view and use the model without having to learn or install NetLogo. As one said, "It provides a painless way of them seeing it working, and then if they want to get into it further they've got the NetLogo file to download. They can go and get themselves a copy of NetLogo." Another subject reported that his organization has a Web site on which they publicize models on a regular basis. A small number reported having submitting to NetLogo's community models page, which allows for sharing but neither collaboration nor cooperation, or to the

OpenABM.org site sponsored by the Open Modeling Consortium.

Code collaboration: Most subjects also reported having collaborated with other modelers. One said that he explicitly engaged in pair programming, “Yeah, we won't be passing the file back and forward, or putting it on a web site and saying, ‘Hey, you have a go now. Let me know when you're finished or anything like that.’ We'll actually just be sitting at the screen together. That would be the most common mode for me, anyway.”

Another indicated that while he and his colleagues often worked from home, they would also work from a shared physical office, which allowed them to discuss issues they encountered in their respective models. “So we had a management team in place and whatnot. But we couldn't have done that if we couldn't get together and hash things out or argue them or whatnot. It would have been a huge impediment towards progress, you know.” When asked to clarify what he meant by “hash things out,” he pointed to the interdependent nature of his collaboration, in that they would debate and discuss the most appropriate way to implement the model. “A lot of the meetings were just figuring out the best way to do it, what sort of formula. How you take a simple situation where you have two agents[1] meet, and one has one opinion, and the other has another opinion. And you say well, how does each change the opinion of the other, you know?”

Cooperation: There were also examples of cooperation — that is, parallel development tracks that were combined toward the end of the project, without a large degree of interdependence during model development. In several cases, this meant using NetLogo’s ability to read “NLS files,” which make it possible to break a single model into a number of separate files. Using such files make it easier to reuse functionality across multiple models and to split tasks among multiple people, in addition to improving the readability of the NetLogo code.

One subject described how he begins with a mock “dummy” model, which then loads and executes the NLS files that the groups are suppose to develop: “And so the big model will say initialize and it then calls initialize for each of the pieces in those NLS files and then it will say go forth and behave […] And as long as those definitions stay the same I can take my NLS file within the context of these other dummy ones and just edit my one file.” In other words, this subject uses the NLS-file capability of NetLogo to allow modelers to work in parallel, even though there are some things that cannot be parallelized.

Domain collaboration: The above description does not reflect the variety of collaborative styles in which subjects worked, or with whom they collaborated. All of the subjects reported that they also collaborated with domain experts, who could verify the accuracy of the model that they had developed, but who didn’t work directly on the model. These domain experts often had little or no understanding of modeling, let alone of NetLogo — but their expertise made it possible to write and write better models. One subject said that he tried to let everyone focus on the thing that they do best: “Let’s just work together and I’ll do my thing and you’ll do your thing and together we’ll have a peanut butter and jelly sandwich that’s delicious with my peanut butter and your jelly.”

Another subject described his experience collaborating with a domain expert. The modeler would write the NetLogo code, while the expert would describe the structure of the model and the rules that determined how the various agents interacted. The modeler distinguished between

[1] In NetLogo, the basic elements are “agents,” computerized objects that can be given commands. These commands can range from changing their location to visual attributes (e.g., color or size), to what rules they should follow when they encounter another agent.

programming in NetLogo and the model, saying that the expert's comments weren't "specifically related to any correction we got in the NetLogo — it was more about the modeling."

Several subjects reported the crucial role played by those who could bridge the gap between the modeler and the domain. One indicated that it was significantly easier to work with domain experts who had at least a basic understanding of programming and computers: "You know, we talked to a sociologist or the economist or something, and they'd give general outlines. We were very lucky to have a sociologist with a mathematics background first of all. That's an important point, because he thought in computational terms."

Another subject described that when his students are given a modeling assignment, one is typically assigned the role of programmer, while the others learn about the subject and become the domain experts. He added that creating a successful model requires more than just technical skills: "We're not just looking for people to demonstrate technical proficiency. We're wanting a question and a model that's built to address that question."

Face-to-face interaction: In all of these cases — sharing, cooperation, and collaboration — subjects largely preferred to work face-to-face with others, but remote access and interactions were not uncommon. One subject said that he normally collaborates in person but that "once a model is reasonably mature, we might go to separate places and pass it back and forward a bit via email." In several cases, subjects met in person with domain experts because such experts were less familiar with computer-based modeling in general, and with NetLogo in particular. Several subjects described sharing models with others via e-mail, but because running a NetLogo model requires the installation and use of the entire NetLogo environment, this was seen as a barrier to entry. One subject said, "I think it's painful in the distance. I mean, that's a problem," adding, "I think it was best to be there and work with him because that's my way of expression."

Iterations and versions: Several subjects indicated that when they are modeling, they work in small increments, making improvements in each iteration. Along the way, they create many versions, which they typically save in files containing a manually determined version number, allowing them to revert to previous versions as necessary. One said, "I've written a lot of derivations of the same model. Now you know, by the time you get to the end, it doesn't look like anything that in the beginning. So I guess from start to finish I have probably done 50 different versions of three different models." Several subjects also mentioned that they often create a family of related models, each of which is a slight variation on the theme.

Discussion

From the beginning, our work on the Modeling Commons has been driven by an interest to better understand the ways in which NetLogo modelers interact with others during the modeling process, and to offer a platform that both facilitates existing interactions and encourages new ones. The interviews validated many of our findings and design decisions to date, indicating that our work on the Modeling Commons does seem to answer many of the needs of NetLogo modelers. However, the data also suggest additional forms of interaction that could benefit social interactions within the Modeling Commons.

On the specific subject of collaboration, the Modeling Commons software seems to offer many solutions to problems and issues that the subjects described: It provides an easy-to-use mechanism for sharing NetLogo models, either privately or publicly. It supports, and even encourages, the rapid creation of many iterations of models, as well as different related versions of the same model, both of which were cited by a number of subjects as part of their development process. It allows modelers to ask questions of one another, and to collaboratively edit models, selectively granting and revoking permissions to particular individuals if the model is not yet ready to be released publicly.

Certain elements of NetLogo development are not currently supported by the Modeling Commons, and these interviews pointed to several of these elements that have now been given higher priority. One of these is the use of NLS files, which make it possible for multiple users to work in parallel with one another, while avoiding the need to cut-and-paste code from one user's computer to another.

But perhaps the most important finding from these interviews, was what we have termed "domain collaboration," between modelers and domain experts. Our work to date, as well as research literature, sees "collaboration" as a single type of activity. However, our interviews found, time and again, that modelers collaborate with two different types of colleagues, and have different types of interactions with them: Fellow modelers, with whom they may develop and improve a model, and domain experts, who provide feedback on the validity of the model based on existing theories and evidence. Some people are certainly both modelers and domain experts, but according to our interviews, this occurs in the minority of cases. Most of the time, domain experts are interested in seeing the model succeed, and in helping it to develop and grow — but they are not involved in the day-to-day development of the model.

If we see collaboration as "interdependence," to use Salomon's term, then the person implementing a model is interdependent with a domain expert. The domain expert cannot create a model alone, but neither can the modeler create the model without a domain expert. Each needs the other, and the modeling process consists of many iterations of development followed by feedback from the expert.

In this way, we see that "sharing" is not merely one type of interaction that a modeler has with his or her peers, but an activity that occurs between iterations of a model's development. Sharing a model with a code collaborator offers the chance to improve the model's implementation but without changing the theory that drives the model. Sharing a model with a domain collaborator will almost certainly result in code changes, but only inasmuch as the theory requires.

It would thus seem that merely referring to "collaboration" does not adequately reflect the distinct types of interactions that we can expect to see in modelers' interactions. We have begun, in our own work, to distinguish between "code collaboration" and "domain collaboration" as two distinct types of interaction, each requiring its own form of support.

We could have used a term such as "expert verification" to describe interactions between the modeler and the domain expert. Given the deep, extensive, and intertwined nature of the work done by modelers and domain experts, we believe that it is fair and appropriate to use the term "collaboration" in our description.

From the interviews, as well as from previous design iterations on the Modeling Commons software, we believe that the Modeling Commons offers adequate support for code collaboration. If we were merely interested in facilitating the development of software, then that might be sufficient. But as researchers working to encourage and advance the state of modeling, we believe that support for domain collaboration will expand the potential audience of the Modeling Commons. Just as the Modeling Commons software offers a variety of communication channels — forums, tags, and collaborative modeling — for code collaboration, it must also provide tools for domain collaboration.

One such channel does already exist, namely the discussion forum attached to a model. Since the

Modeling Commons was opened to the public, we have seen some limited use of that forum, in which users did discuss the implementation details of models. However, additional design and features aimed at domain collaborators will distinguish the Modeling Commons as a place for modeling, rather than just for programming, offering tools for where concepts and coding intersect.

We are also considering the addition of a model-specific wiki page, editable by anyone with write-permission for the model. This would provide a space in which authors can communicate, outside of the discussion forum, on the issues related to the model. Offering a free-form space in which to suggest and consider ideas, specifically for collaborators who are not programmers, may encourage deeper online collaboration than is currently possible.

Another possibility is a concept-mapping tool, which would allow domain experts to explicitly diagram, categorize, and describe the various ideas involved in a particular model, for the joint benefit of the domain expert and of the modeler who must translate such ideas into programming code.

Another option would be to provide, via the Modeling Commons, an interface to the BehaviorSpace program that comes with NetLogo. BehaviorSpace makes it possible to run a model many times, varying the parameter values with each run, to better understand how the model will run in response to different inputs. BehaviorSpace can thus provide domain experts with feedback on the results of implementing their ideas, without having to modify the code or ask a programmer for assistance.

Finally, improving the social tagging system that is currently in place will make it easier for domain experts to find models in their field, and then to help modelers to improve them.

Conclusions

We undertook this study before officially launching the Modeling Commons, in order to understand the current state of social interactions among NetLogo modelers without use of our platform. We believe that these findings confirmed our previous work, and that the design of the Modelling Commons will support many of the interactions and needs of NetLogo modelers.

That said, other findings indicated that NetLogo modelers regularly consult with domain experts, often during the modelling process itself. This "domain collaboration," as we have described it, is an important part of modelling, and helps to distinguish modelling from simple programming. These findings indicate that we need to think more about providing affordances for expert-coder interactions, such that the Modelling Commons will be useful not only for the programmer-modelers, but also for the domain experts who play a critical role.

We expect to implement a number of new features to support such interactions in the near future, and will monitor use of these features, using both the system's automated logfiles and by interviewing users, to learn if they have made it easier to collaborate with domain experts.

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Cultivating Constructive Mindset in World Museum, collaboration across cultures and generations

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Abstract

In World Museum, connecting universities/schools in many countries for creative collaboration across cultures and ages to create Scratch (Resnick, et al, 2009) animations. We propose a framework that addresses learning as embedded in a complex system of social relations, based on "constructive mindset", a generalization of "growth mindset" (Dweck 2007), as one's belief that one can construct the social/technological systems in which one is involved. Based on the framework, we analyze several cases of collaboration projects in World Museum. We found that the students' passions (the extent of systems for which one has constructive mindset) expanded from products to relations with people, to meaning of the products, and to learning environments. Based on these results, we identify some design principles for guiding the development of constructive mindset through cross-cultural and cross-generational collaboration.

Keywords

Collaboration; Constructive Mindset; Cross-cultural; Scratch

Constructionism and the need for global visions and passions

It is often when a system breaks down that we can learn much about designing the system. On March 11th, 2011, a huge earthquake and tsunami hit the northeastern coast of Japan, claiming tens of thousands of lives, and leaving hundreds of thousands without home, work, family, or friends. As the tragedy continued, many people who had interests only in things around them seem to have expanded their visions and began to pay attention to what's happening in the affected areas. Many people who had regarded social activities as someone else's business are now expressing their passions to get involved in activities to help the struggling people. Many people have designed creative ways to coordinate the efforts of these people trying to find ways to send necessary resources, like food, energy, and other necessities to the areas in need, or to help people rebuild their homes and jobs.

In the process of these efforts to support ourselves, when we could no longer rely on many of the social and technological systems that seemed to work well in stable situations, we have realized that we have to listen more carefully to each other, watch more carefully what's happening, and, most importantly, trust each other and support each other, more than we used to. We are realizing that the systems that we had relied on were designed so that we did not need to listen and watch so carefully, and did not need to trust and support each other so often. In other words, these systems have broadened the extent to which we rely on, but at the same time narrowed our visions compared to the extent to which we rely on.

We have also begun to understand the danger of usable and reliable systems, which we have been trying to design since the publication of “User Centered System Design” (Norman & Draper, 1986). Those working at the Fukushima nuclear power plant at the time of the breakdown caused by the tsunami had difficulties in understanding and handling the situations. They had never experienced major failure of the system; the enormously complex system had kept functioning for decades. The users of reliable systems tend to have narrower vision than the designers. As the users of the system, the operators did not need the designers’ visions, until the breakdown.

These are just a few examples of many opportunities we have found in post-earthquake Japan, to learn by constructing systems. As Dower (2000) pointed out in his examination of post-war Japan, in the face of unexpected difficulties, there emerges a space in which we can re-think everything in new ways. These experiences illustrate the importance of constructionistic learning in which people learn as builders of systems, not just as users (Papert, 1993). This applies not only to constructing technological and knowledge systems, which were the main focus of Papert, but also to constructing social systems. As Norman (2010) argues, design education must incorporate complex social systems.

As a culture matures and its social systems become stable, it seems inevitable that people will start relying more on the systems than themselves. As Turkle (2011) points out, even today’s social media can leave us less connected than before. The question is how we can turn users to builders/designers, not only of artifacts but also of social systems. Do we need such a tragedy to be able to learn creatively? Fortunately, in today’s world, meeting people from different cultures or generations might provide us with opportunities to re-think what we have taken for granted.

In this paper, we will describe some projects we have coordinated in which students collaborated across cultural and generational boundaries, and discuss how we could cultivate constructive mind of the students by expanding our visions and passions, without facing a tragedy.

. A theoretical framework: mindset, vision and passion

In order to address the question of how we can cultivate constructive mind, we first propose a theoretical framework to guide our design of the collaborative activities. Dweck (2007) introduced the concept of “Fixed vs. Growth Mindsets”. With a fixed mindset, one believes that one’s intelligence is fixed and cannot be changed by efforts, whereas with a growth mindset, one sees the intelligence as malleable, something that can be developed by efforts. We would like to generalize the concept of mindset to the systems that we construct or use:

- **Fixed mindset**: one can have a fixed mindset about a (social, economical, or technological) system and believe that the system is fixed and cannot be changed by one’s own actions.
- **Constructive mindset**: one can have a constructive (growth) mindset and believe that the system is malleable and can be modified, re-designed, or even created by one’s own actions.

This is a generalization of Dweck’s theory dealing with intelligence because we can regard intelligence as part of the complex social systems.

We are usually aware of only a fragment of the enormously complex social, economic and technological system that we depend on, and we can usually imagine being able to change only some part of the system. In other words, we have constructive mindset about some part of the system, and fixed mindset about other parts.

Let us introduce two concepts, vision and passion to distinguish those things that we have fixed mindset about and those things that we have design mindset about.

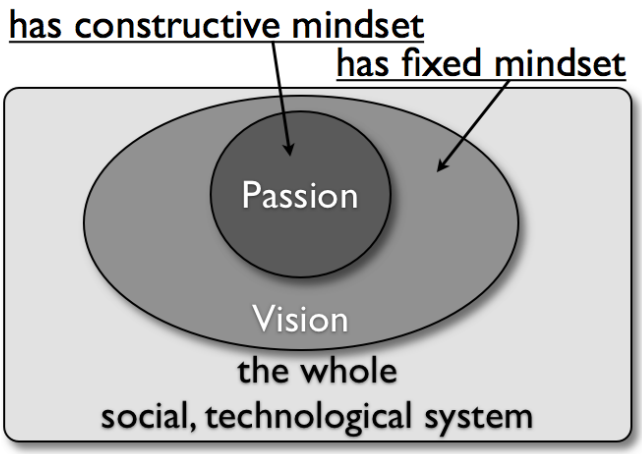

Figure 1. Mindset, Vision and Passion

- **Vision**: Vision means the extent of the system which one is aware of and interested in knowing or understanding, regardless of whether one has a fixed or constructive mindset about it.
- **Passion**: Passion means the extent of the system which one has constructive mindset about. In other words, passion means the things that one is interested in creating or influencing by one's own actions.

J. F. Kennedy's "ask not what your country can do for you - ask what you can do for your country" is an expression trying to expand people's passion, rather than their vision, by encouraging constructive mindsets.

One usually has a wider vision than passion. For example, one might be interested in knowing about the functionality of software that one uses, but might never imagine that s/he can create or modify the software. One may love listening to music but may never imagine one can compose or play music. (Figure 1)

Having vision would seem to be a necessary condition to have passion, because one can be interested in creating things only if one is interested in those things in the first place. ("Think globally, act locally" is an expression to encourage wider passion by having wider vision.) Therefore, we have designed the collaborative activities so that the expansion of students' vision guides expansion of their passion. (Figure 2)

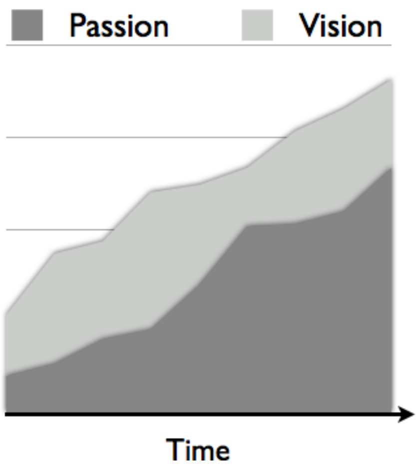

Figure 2 Expansion of Visions guiding Passion

Learning through Collaborative Construction

We have designed and coordinated collaborative acitivities for learning to cultivate constructive mindset and expand passion in students. In several cross-cultural and cross-generational inter-school collaborative projects, in which collaborating with people of different cultures or generations has been useful for broadening students' perspective and creativity in the design process (Miyata et al., 2010, 2009).

We designed activities in which students constructed some artifacts. Constructing an artifact is embedded in a social process of constructing relations among the people who create, view, use, or work upon it. Furthermore, we designed collaborative activities because collaboratively constructing an artifact is a learning process in which the members try to communicate ideas through the artifact to discover new relations and meanings. We can expect that in collaborating across cultural differences, one can expand one's visions in trying to understand each other, and expand one's passion in trying to develop the ideas together. In this sense, the collaborative designer is not just constructing an artifact, but also constructing the learning of the people involved. In collaborating across generational differences, older or more experienced members can construct a learning environment for younger or less experienced partners. In this sense, the collaborative designer can also be an education designer.

Tools for Collaborative and Constructive Learning

Scratch as the tool for expression: We used Scratch (Resnick et al. 2010) as the tool to express and communicate ideas across cultural and generational boundaries. Scratch (Figure 3) is suited for this purpose because it is:

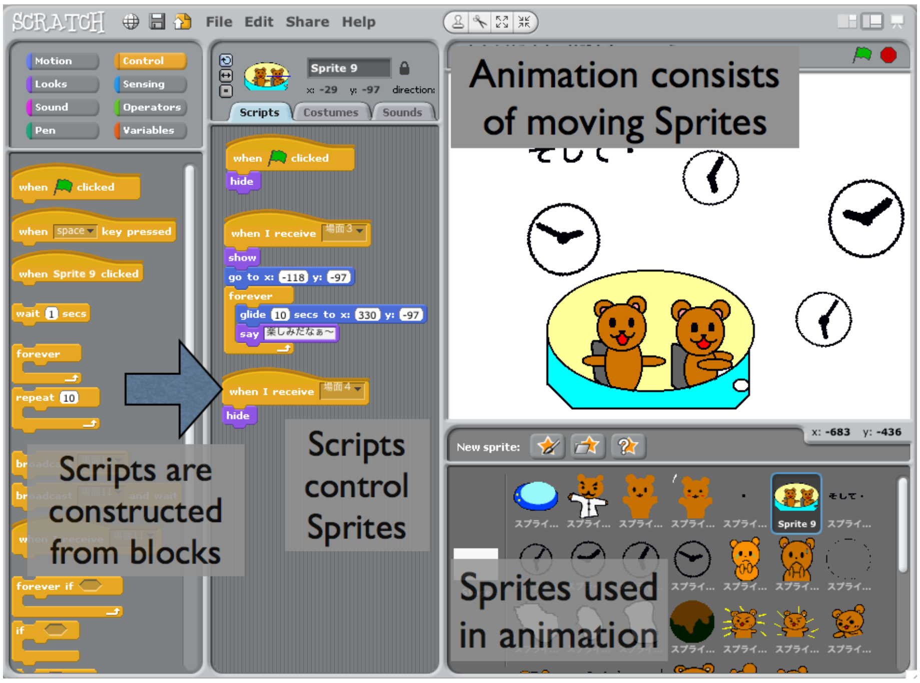

Figure 3 Scratch Interface

- **tangible**: with its block-based interface for programming, which avoids syntax error, Scratch is easy for beginners and children.
- **meaningful**: with its well-designed blocks as well as ability to design visual and sound objects, Scratch allows many different kinds of expression for different interests and backgrounds that the user may have.
- **social**: with its multi-language interface allowing over 50 different languages, and its social network site with hundreds of thousands of users uploading over two millions of projects and communicating as well as collaborating with each other, we can have interaction with multi-cultural audience.

Social network for sharing reflection: In order for students with different cultural and generational backgrounds can collaborate with trust, each member should be able to share ideas and feelings often. For this purpose we used a Social Networking System as well as video chat system (like Skype) and streaming service (like Ustream) to ensure communication among the members as well as the audience from outside.

World Museum Project

The first collaboration using Scratch started when a group of university students collaborated with a group of students in an elementary school in Massachusetts, as a part of Scratch Day in May, 2010. Since then, this small collaboration project has grown to involve students from at least five universities and ten elementary schools in different countries, and other children and adults from local community as well as from different areas. These projects are now collectively called "World Museum Project" to signify its global vision and passion. In the following sections, we will take a closer look at what happened in some of these collaboration projects, in terms of the framework outlined above.

Case study A: Animating Cartoons

In 2010, group of college freshmen and a group of 5th graders collaborated. The 5th graders designed animations about environmental issues expressed as hand-drawn cartoons (Figure 4). The college freshmen turned the cartoons into Scratch animations (Figure 3).

Figure 5 Cartoon describing an animation

Analysis: We compared two groups of freshmen and found that animations based on the children's cartoons were more sophisticated than works by another group who created Scratch projects freely without collaboration. The works of collaboration used 8 times more scripts and 4 times more sprites than the non-collaborative works (Figure 5). Also, they used more blocks in the "control" category used to construct loops and conditional branches. (Figure 6) Clearly, the students who collaborated with the children learned more about programming in Scratch (both in breadth and depth).

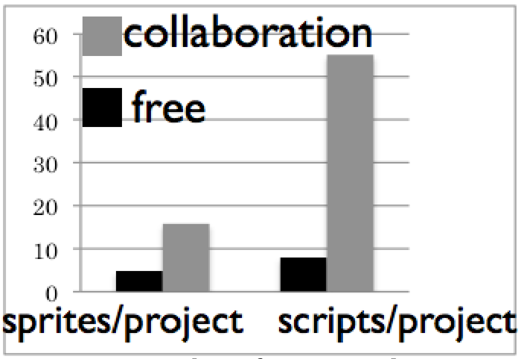

Figure 4. Number of sprites and scripts in collaborative and free projects

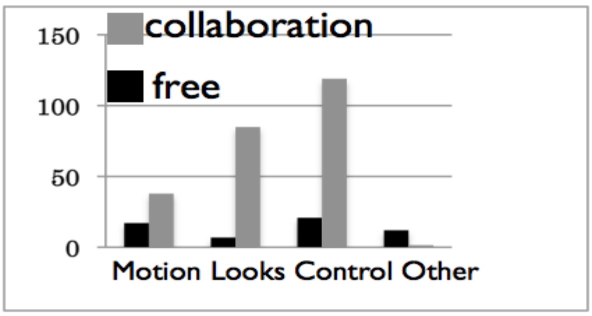

Figure 6. Number of blocks of different types used in collaborative and free projects

An analysis of their comments in the SNS in which they reflected on the experiences indicated that the passion of the college students expanded during the course of collaboration. In the following, we try to characterize their mindsets in terms of the changes in their passions.

Four levels of constructive mindset

The changes in the passions described in Case Study A above can be generalized as going through the following four levels.

- **Product-oriented mindset**: At the beginning, their comments in the SNS were concerned mainly with making the animations themselves. Their mindset was focused on constructing an artifact.
- **People-oriented mindset**: After they communicated online (video/voice chat) with the children and realized their expectations, they started to work very hard to make the children happy, as reflected in their comments in the SNS such as "I will work hard to fulfill their expectations" or "It was fun to create the animation just like they illustrated". Their mindset was focused on constructing relation with the audience through constructing the artifact.
- **Meaning-oriented mindset**: Their comments also mentioned communication with the children about the meaning of the animations that they were working on, such as "I was impressed with the child's thinking", "talking with the children gave me some new ideas". Their mindset was focused on constructing the meaning of the artifact.
- **Learning-oriented mindset**: Interestingly, there were many comments from the children mentioning that they were interested in creating animations themselves. Some of more experienced students responded by trying to design their animation scripts so that the children can understand the process of how the animations worked, in order to inspire the constructive mind in the children. Their constructive mindset was focused on facilitating learning in the design process

In the following sections, we will describe more cases in our collaborative activities and analyze some of the collaboration projects in which the students' constructive mindset developed.

Case study B: Inter-disciplinary Collaboration

Inter-college student teams from four universities collaborated in 2010. The students were from C. University (computer engineering major), S. University (culture and information), T. College (education), and C. Institute (information design). The goal of the project was to create educational materials for primary school students.

Figure 7. Collaborative Scratch Project

The project started in October, 2010, by each university group creating Scratch projects to introduce themselves and their campuses to each other [**People-oriented**]. In November, a number of project themes were proposed from the students, and three inter-college teams were formed each of which worked on a theme. They collaborated through December and finished their projects in January, 2011. The four groups had weekly classes on different days, so the communication was done mostly on an SNS. At the end of each class, each team uploaded their Scratch projects created so far on the Scratch website, which were then embedded in a blog entry explaining what they had done. Members of the other universities read the blog and wrote comments or questions.

Analysis: In one project, it was difficult during the first two weeks for team members from two universities to understand what each other was trying to do. So they decided to communicate via Skype [**People-oriented**]. They later commented that they reached a mutual agreement about the goal of the project in this Skype session [**Meaning-oriented**].

In many of the projects, it was observed that the students tried to coordinate the team projects so that the specialty areas of different members can contribute effectively to the projects **[Meaning-oriented**], such as a language student who turned a project multi-lingual, or a computer engineering student who added explanations so that the children could learn how to make them [**Learning-oriented**]. As a result, the design students learned to view their role in a wider social context, while the other students learned to view their own areas in the designer's perspective.

Case study C: World Studio Spring

During the year of 2011, we had two series of workshops in which children from different geographical areas collaborated. During the first series of four sessions "World Studio 2011 Spring", held in June and July, we had children mainly from the local community of Toyota.

Analysis: After the first session had ended, a family who participated from Osaka (150km away from Toyota) started to organize their own weekly workshops in Osaka. [**Learning-oriented**]:

Case study D: World Studio Autumn

For the second series of four sessions, held in October and November, we designed the activity so that each participant could first work on a separate piece of work, but all the pieces were then integrated into a larger work of art, in this case an animation with a large screen size (1600 pixels wide compared to 480 pixels of the standard Scratch screen). The group in Toyota and the group in Osaka collaborated with each other communicating through Skype and through uploading their works to the Scratch site. They also communicated with children in Massachusetts by sending photos and uploading their works. The animation was based on a large (8m wide) mural created

Figure 8. US and Japanese children collaboratively animated "Kids Guernica" mural

jointly by children in Nagasaki, Japan, and children in Florida, USA, in the 'Kids Guernica' project (Figure 9). Each participant chose a few of the objects (people, animals, birds, etc.) drawn in the original mural and created an animation by giving movements and/or visual/sound effects to each object.

Analysis: When all the objects were put back onto the original background, they realized that they needed to negotiate with others about the movements and visual/sound effects that they had designed. For example, many children put sound to their objects but mixing all the sounds together sounded like a chaotic noise, so they started to discuss how to coordinate the different sounds. While they put the sounds that they liked when they designed the animations of single objects [**Product-oriented**], when they tried to mix them, they had to think about the meaning of putting the sounds in the final animation. [**Meaning-oriented**]

Case study E: World Family Studio

After the second session had ended, the parent group in Aichi started organizing regular monthly workshops called “World Family Studio”, so that their children could continue the activity. For the December studio, the parents chose animated Christmas tree, which allowed the children to create animated ornaments based on individual interests, and then put all the ornaments onto a tree (Figure 10).

Analysis: Initially, the Japanese and the American children focused on creating their own trees. **[Product-oriented]** When they saw what each other was created, they were excited and started to work hard. **[People-oriented]** Next, they wanted to integrate their works. As they exchanged ideas for how to integrate, they came up with many interesting ideas, such as making a forest, and in the process they mentioned about the similarities and differences in their creations and their meanings. [**Meaning-oriented**]

Figure 9. Christmas Tree by US and Japanese children

Case study F: High School Students and College Students

In July 2003, a group of high school students participated in a workshop organized by a group of college students as a part of an international event called “World Youth Meeting” (Kageto et al., 2003). The high school students and college students kept communicating online using a chat system and a BBS (bulletin board system) after the workshop. After communicating online for four months, which resulted in over 6,000 chat lines, the high school students designed and organized their own workshop in their school in November, so that their schoolmates could have the same experience they had had in the workshop that the college students designed for them.

Analysis: An analysis of the chat lines revealed that college students tried to facilitate communication of the others more often than the high school students, indicating that they had wider passions. It also indicated that the visions (the extent of relationships to which they mention in the chat) of both the high school students and college students expanded during the four months period (Miyata et al., 2009). These results can be interpreted in the new framework that the college students facilitated the passions of the high school students, which , as a result, expanded to facilitation of the learning of their schoolmates **[Learning-oriented]**.

Discussion

In many of these cases, the students seemed to have product-oriented mindset at the beginning, but as they communicated with their partners, their mindset changed to people-oriented, seeing the partners as user/audience of their products. In Animating cartoons (case A), the college freshmen's writings in the blog changed from comments about the products to comments reflecting their wish to fulfill the children's expectations after they talked with the children about their products. In "World Family Studio" (case E), the Japanese children were observed to start working very hard after they saw what the American children created. Their parents and the student staffs agreed afterwards that the children's attitude changed when they became aware that the American children will be looking at their works.

Design Principle (A): Create then Connect

These two cases suggest a design principle "Create then Connect": When two groups of students collaborate, their visions and passions will not be oriented toward (not interested in) collaborating with the partners initially, so they will be more interested in creating something they like. After both groups have created some products with enough passions, they will be interested in what the partners will comment about them (they will have people-oriented mindset), and will be more ready to appreciate what the partners have created. If you connect the passions of two groups by letting them share their works with each other, they are likely to keep interacting because they are now interested in each other. In some cases in which only one group created products, sharing it with another group did not lead to any collaborative activities.

When we succeeded in connecting the passions of multiple groups, they tended to continue their interaction. However, they soon discovered that their passions were not exactly the same. In the case of the Inter-disciplinary Collaboration (case B), the team of students from two universities who felt lost as to what they should be doing, a video chat with Skype helped them to discover a difference in what they were trying to do and led to a mutual agreement of the goal of their project. In this case, the difference in their passions led them to have meaning-oriented mindset (focus on shared meaning) and, as a result, expanded their vision, and then passion. In the other team of students who had to figure out the roles of students from different areas, they could appreciate what they had learned in their respective areas in a broader vision of the project, and, as a result, expanded their passion by contributing.

Design Principle (B): Keep Visions Open

The most exciting moments in these collaborative activities are when the participants acquire learning-oriented mindset, that is when they start to construct learning environments on their own. The high school students designed a workshop for their schoolmates (case F). The parents designed World Family Studio for their children (case C). These cases are important because it means that they have acquired constructive mindsets for social systems, not just inside their classrooms or workshops which someone constructed for them. They now believe that they can construct some part of the world where they belong.

This suggests another design principle "Keep Visions Open". As the designers of the collaborative activities, we should have visions of not just within the activities (classes or workshops) that we design, but also of outside the activities so that the participants can extend their mindset, vision, and passion to the daily lives of themselves, such as the families, schools, and communities that they come from. In our workshops, we encourage the participants to bring in their social contexts into the workshops, and try to facilitate them to connect what they experience in the workshops to their other activities in life.

Summary and Conclusion

We started out by a proposal of a framework of fixed vs. constructive mindsets, generalized from Dweck's mindset concept. Then we described some case studies of collaborative cross-cultural or cross-generational projects designed based on the framework. In analyzing how visions and passions of the participating students expanded in the collaborative activities, we could characterize the students' constructive mindsets as expanding through four levels: (1) product-oriented, focusing on designing artifacts, (2) people-oriented, focusing on the relation with the user/audience of the artifacts, (3) meaning-oriented, focusing on the meaning of the artifacts in the social context, and (4) learning-oriented, focusing on facilitating learning of themselves and others. Finally, we identified two design principles that can be useful in designing the flow of collaborative activities. (A) Create then Conenct, and (B) Keep Visions Open.

Acknowledgements

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Of particles and bikers: Junior triathletes invent drafting tactics with agent-based models

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Abstract

The study involves the design and research of a model-based triathlon training unit about the aerodynamics of biking in groups (drafting), using this knowledge to construct new drafting tactics and testing them out in practice. The study was conducted with two groups of 14-17 years old youth: the Israeli national team (experts; 5 male, 3 female) and a local team (hobbyists; 5 male, 3 female). The goal was to explore whether using agent based models of bikers and air particles to learn about principles regarding drafting and in order to design new tactics could be used to enhance athletes' understanding and performance, and whether this depends on expertise. The athletes' designs introduce new tactics of drafting that incorporate an idea of uneven load distribution. Results of testing out these designs show superior performance, as seen in the shorter times, lower pulses and effort. The expert team invented a greater number of improved tactics.

Keywords

Agent-based models; Complex systems; Competitive sports

Introduction

In this proposal, we describe research into young triathletes' invention and execution of new drafting tactics, through learning with computer models based on a complex systems approach. It is based on an assumption that understanding the causal structure of action and interaction supports improved skill in action (Schmidt & Lee, 2011)

The study focuses upon the phenomenon of drafting in road bicycle triathlon competitions. Drafting is when a group of cyclists move together and can be applied when it's a legal drafting competition (Figure 1). It is used to gain energy advantages in moving through the air (Hausswirth & Brisswalter, 2008). As such, it touches on the domain of competitive sports training and physical education. The phenomenon of drafting offers unique insights into the delicate balance between competition and cooperation among collectives, where at every time step, each athlete needs to decide whether to desert the group or stay. On one hand, drafting offers up to 40% savings on energy expenditure, rising with the biker's speed (McCole et al., 1990). On the other hand, the group speed may slow a biker down too much; in which case, a smaller group may "break-away" usually around a bend in the road. Thus the persistent question is "stay or break away", where the answer can change at any moment. In the particular sport of triathlon (sequence of swimming, biking and running), biking at a less than maximal rate and minimum energy expenditure is particularly advantageous in saving energy for the last leg of the competition, the running portion. Finally, drafting is in fact a general phenomenon viewed among racing cars, cross-country skiing, tailgating trucks, birds, fish and more.

Figure 1: Drafting cyclists (Belgian Tourniquet formation - successively each cyclists leads the group)

The phenomenon of drafting was selected because of long-standing difficulties in its understanding by athletes[1] and the large energy advantage it offers. The most-commonly understood concept is that cycling through air causes the dynamics of the air to change around the biker in a way that forms a low-pressure area in the back and eddy streams (vortices) in the back/diagonals. Having another cyclist move in very close (professionals approach up to a number of inches!) into this region means there is low pressure in front of him, decreasing the air's resistance to his motion. Additionally, having the second cyclist behind the first one reduces the turbulence by smoothing the eddy streams in the back-diagonals and reducing the drag on the first cyclist, though to a much lesser extent. Based on this idea, most drafting tactics involve a one-dimensional formation made up of "cyclist-behind-cyclist" repeating units. A simple tactic in drafting that is commonly used is a single line of closely packed bikers, forming a diagonal in case of wind. The most efficient tactic to date is the Belgian Tourniquet, where the cyclists form an ellipse (essentially a bent line) and rotate it, so that successively each cyclist leads the group (Hausswirth et al, 2001). In this study, we wish to expand beyond these simple tactics and incorporate additional advantages one may obtain from a deeper understanding of the aerodynamics of clustered biking. This approach would be two dimensional, incorporating reasoning not only about the pressure between a front and back biker, but also along the sides. As hinted in the "smoothing the eddy streams" idea above, where the bikers may be able to manage the air collectively, by transforming turbulent flow to laminar (smooth, less resistant) flow.

We have developed a three-day training program "of particles and bikers" in which the athletes themselves invent new drafting tactics and test them out, based on constructionist principles of learning, propelling invention and construction as a superb form of learning (Papert, 1983).

The training unit is framed within a complex systems approach to understand the aerodynamics of drafting. According to this approach, a system's behaviour arises from the local interactions

[1] The second author is an ITU competitive triathlon level 2 coach, with many years of experience in training, was the triathlon national team head coach and today, trainer of coachers. This claim is based on his personal experience and through his many conversations with other coaches.

between its parts (Viscek, 2002). Advantages to learning within this approach involve a greater generativity of understood phenomena from a smaller set of principles (Blikstein & Wilensky, 2007), thus supporting a deeper understanding (Levy & Wilensky, 2009). This approach is implemented in the study with computerized NetLogo (Wilensky, 1999) agent-based models: one with moveable cyclists and air particles (Bacalo, Kakoon & Levy, 2011) and one based on an existing NetLogo model of birds flocking (Wilensky, 1998) with an addition of air particles and their interactions with the birds (Hirsh, Haviv-Gal & Levy, 2011) (see Appendix). Effort is viewed as the rate at which air particles hit a cyclist: when the rate is greater, the air resistance to his motion is greater as well. In representing the aerodynamics of drafting, these models are much simpler to understand with respect to the classical approach that is based on fluid dynamics. One needs to understand only simple two-body collisions (between bikers and air particles; modelled similarly to two billiard balls in motion colliding with each other). This makes the notions of the flow, waves and pressure topographies an emergent result of these interactions, rather than principles one needs to incorporate into reasoning about the system ab initio. These models were used as an explorative medium to understand the phenomenon of drafting. Furthermore, they are used as a constructive medium to design new tactics in drafting, by creating a variety of spatial formations of the cyclists among the sea of particles.

We expected that learning would be deeper and the resulting tactics would be more variable also through harnessing the athletes' prior knowledge of competitive bicycle riding (Williams et al, 2010; Mann et al., 2007). To test out this idea, the study was conducted with two teams of differing levels of expertise – the Israeli youth national team (experts) and a local team (hobbyists). Whether and how prior knowledge could be activated and used becomes comparable.

While the study addresses the possible learning advantages of such training, the main goal is to obtain better results in a competition. Thus both biking performance and cognitive measures are employed to gauge learning.

Research Questions

The research project addresses various aspects of learning and the learning process. In the current paper, we report on a subset of these, guided by the following research questions:

- How does young triathletes' drafting in biking performance change as a result of training with the "Of bikers and particles" program in terms of pulse, effort and time?
- What is the relationship between expertise and change in performance?
- What typifies new drafting tactics invented by the triathletes?

By the time of the conference, it will be possible to report on additional results that include the triathletes' changed understanding of the aerodynamics of drafting and how it relates to changes in athletic performance.

Method

Participants

Participants included 15 junior triathletes from two teams that trained separately. Their ages were 14-17 years old youth: the Israeli national team (experts; 5 male, 3 female) and a local team from the north of Israel (hobbyists; 4 male, 3 female). The national team triathletes have been training for over three years, 7-12 training sessions a week, 15-20 hours a week with much experience in national and international competitions. This team trains at a boarding school for gifted youth in sports. Some of them are the national champions for their age groups. The local team triathletes have been training for at least a year in an after/before school program, 5-8 training sessions a week, 8-12 hours a week. They have participated in at least five competitions. A prior requirement was fluent use of computers and parental consent.

Research design

The study was conducted as a comparison group pretest-intervention-posttest design. It commenced about 1.5 months into the training season. Two teams of athletes of differing initial abilities and practice participated separately in an identical sequence of training, made of up of two consecutive days, and then, a month later, one more day (Figure 2). This paper focuses on the first two days.

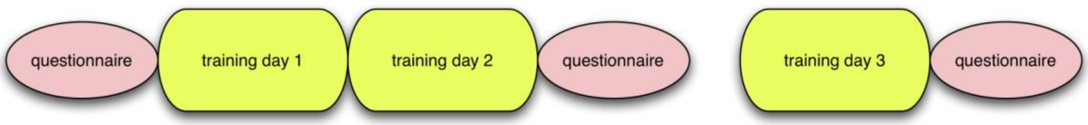


Figure 2: Research design

Training sessions

A triathlon training program named "of particles and bikers" was created. It is made up of some short lectures (e.g. on the relationship between pulse and effort), several discussions, exploring computer models of flocking birds and bikers in various configurations and then using the models to create new efficient configurations (Appendix), testing them out on the road (five testings, four heats each) and collaborative analysis and discussion of the pulse, time and effort data. Training sessions were based on the following design principles: (1) Trusting that the athletes can invent new and better drafting tactics, based on their experience and motivation; (2) Anchoring in a physical world phenomenon, biking in formation; (3) Successive shifting between theory and practice, and relating the two explicitly – designs were tried out with the models, discussed and soon tested in practice, this process repeating five times; (4) Beginning with two distinct representations of the phenomenon (collision interactions; bird flocking) and gradually merging the two; (5) Using measurable performance goals with respect to which understanding is gauged.

Data collection tools

Several forms of data and its collection are described (Table 1).

Research variable	Data collection tools
Performance in drafting	Time to complete a constant distance of flat road riding
	Pulse measurement right after cycling
	RPE (Rate of Perceived Exertion) effort self-report
Creative products	Athletes' invented tactics for drafting
Conceptual understanding of drafting	Questionnaire administered three times
	Interviews with athletes during training
Attitudes towards drafting	Questionnaire administered three times
Qualitative process data	Videotapes of all the training sections

Table 1: Research variables and data collection tools.

In this study we focus on the triathletes' performance in drafting and their creative products. The athletes wore the pulse meters and took a reading within a minute of finishing each heat. The basic pulse at the aerobic threshold was subtracted from the reading to make the results comparable across participants. Similarly, RPE effort results had a basic effort reading (single riding heat) subtracted from them.

Results

In this section we report on the athletes' designed tactics and their performance in drafting.

The triathletes were excited by the opportunity to participate in the design of new tactics. The training sessions generated much interest in the broader community.

Figure 3 displays the work of one athlete as he drafted a few ideas on paper before testing them with the model. Top-left configuration is the final one. However, reaching this design, one can see elements in the other drawings: bottom-right is an attempt to incorporate internal motion into the design that didn't make it to the final design; middle-right we see two staggered columns – containing one-behind-the-other units and diagonal relative positions; bottom-left is a configuration that he used in the final design. The final design elaborates on this by adding direction of motion and the names of the triathletes in each position (the strong ones are in the front; the national champion is in the middle).

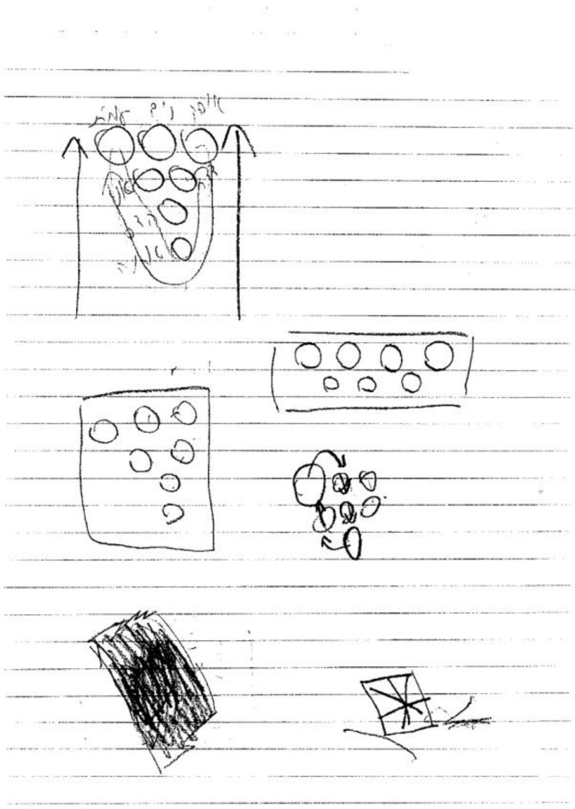
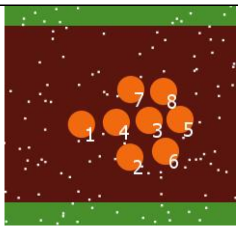
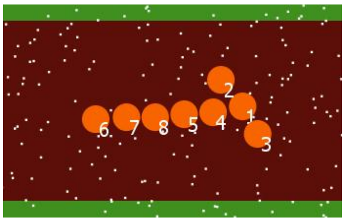


Figure 3: Working draft of a design in the making.

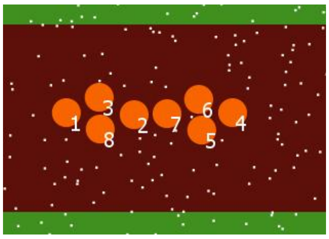
Eleven of the triathletes' initial designed tactics were analysed. All tactics are new in terms of being unfamiliar in the sport. They fall into four general forms (Figure 4):



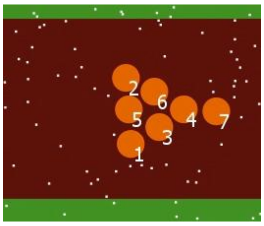
Mallet: A rounded shape with a tail (some called it the flower) has the weaker riders in the middle, wrapped from all directions (5/11 designs).



Hammer-head: A diagonal of stronger riders leads the pack; a column follows them, with the weaker riders up ahead (3/11 designs).



Two-headed: The front triangle are the strongest riders; the ones in the middle are the weakest; the triangle in the back are of medium strength (2/11 designs).



Arrow-head: One rider the front, with rest following at diagonals of the previous ones (2/11 designs).

Figure 4: Categories of invented tactics (Day 2, initial designs). The riders (orange circles) are moving from left to right. The air particles are white. Number of designs in each category are in parentheses.

Figure 5 portrays the designs by features they contain. Three features were included in all designs. One is the use of one-behind-the-other elements, a feature they had known from prior experience. Two features relate to a division of labor that is distinct from the classical Belgian Tourniquet: rather than divide the leading time equally, the weaker riders do not lead at all, as they will slow down the group. The weaker riders are “wrapped” in a variety of forms by the rest, so they need to expend very little energy in the process. This idea is novel in the domain. While most designs tried to benefit the individual riders, only half considered the global shape of the group by making it aerodynamic.

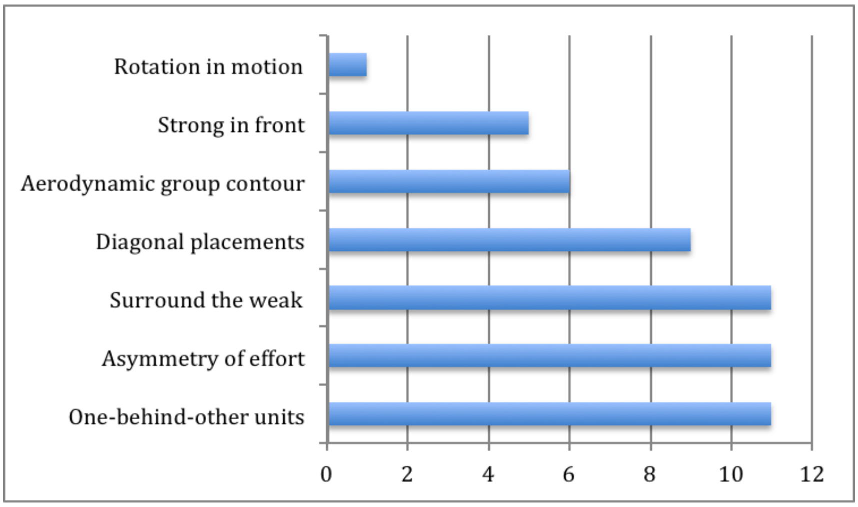


Figure 5: Features of triathletes' designed tactics (initial designs on training day 2)

Table 2 presents the triathletes' biking performance results in the variety of tactics they had designed and selected to try out on the second day of training. The main comparison is between the invented tactics and the Belgian Tourniquet (hence, BT), a commonly used tactic. This comparison shows that for the hobbyists, one invented tactic (Invented tactic 4) was faster than the BT, and the rise in pulse and effort were smaller. For the experts, all four invented tactics were faster than the BT. However, the rise in pulse was also higher and the effort expended was similar. Therefore, triathletes using the model to form new tactics succeeded at designing more efficient tactics than those commonly used. This effect is stronger for the experts than for the hobbyists.

Group	Hobbyists[1]			Experts[2]		
Heat	Time[3]	Pulse[4]	Effort[5,6]	Time	Pulse[4]	Effort[5]
Single	4:50	58 (49)		3:52	15 (29)	
Belgian Tourniquet	4.09	39 (22)	1.9 (2.1)	3:28	45 (17)	-0.9 (1.1)
Invented tactic 1	4:55	53 (21)	3.7 (3.0)	3:15	62 (27)	0.0 (2.0)
Invented tactic 2	4:57	16 (18)	-3.2 (3.7)	2:50	60 (20)	0.3 (1.9)
Invented tactic 3	5:22	26 (16)	-2.2 (4.1)	3:14	53 (21)	-1.2 (1.3)
Invented tactic 4	4:08	21 (22)	-0.3 (3.9)	3:10	58 (22)	-0.8 (1.2)

Table 2: National team and local team group drafting performance results.

[1] – Local team

[2] – National team

[3] – The hobbyists rode for a longer distance of 2 kilometres. The experts rode for a shorter distance of 1.5 kilometres. This results from contextual constraints of the local geography and roads, as a safe flat length of road was necessary.

[4] – Subtraction of aerobic threshold pulse as baseline, measured after warm-up ride

[5] - Subtraction of aerobic threshold effort rating as baseline, measured from first single heat

[6] – Effort is measured on an RPE (Rate of Perceived Effort) scale

By the time of the conference, we will have finished analysing the learning resulting from the training unit based on the questionnaires and interviews and will report on these as well.

Discussion

This study approaches learning as evidenced in athletes' design of collaborative action in competition and in their execution of these designs. We have used a complex systems approach to the aerodynamics of drafting while biking in a triathlon to use and create several models that offer a simple way of making sense of the system. We have also used agent-based computer models as a creative medium for the athletes as they designed new drafting tactics.

We have found that the athletes introduced several new tactics into the field of competitive bicycle riding in triathlons. These new tactics are based on an idea of uneven load distribution among the riders, by having the stronger riders work harder than the weaker ones. They used a variety of spatial configurations to implement this general idea. What characterizes their designs is a greater resolution in viewing the air surrounding and interacting with the bikers. Being able to discern differences in such interactions as a result of position in the configuration supported a more detailed view of the aerodynamics of the group and individual motion. They then used this understanding to create and test new forms of action that harness this greater resolution to bettering the group's speed and effort. They continued using the well known principles of keeping behind somebody else and smoothing the drag by moving on the diagonals. However, they incorporated a variety of ways by which the slowest riders would not slow the group, mainly by nesting them within additional riders.

Execution of these tactics showed a difference between the two teams. The experts (youth national team) were able to generate several distinct tactics that were superior to the classical most efficient one, while the hobbyists (local team) could produce only one. As described in the introduction, greater expertise involves more efficient and adaptive action. Moreover, it is possible that the experts greater experience in competitions and practice, results a broader knowledge base from which to draw ideas that could be incorporated into the new tactics.

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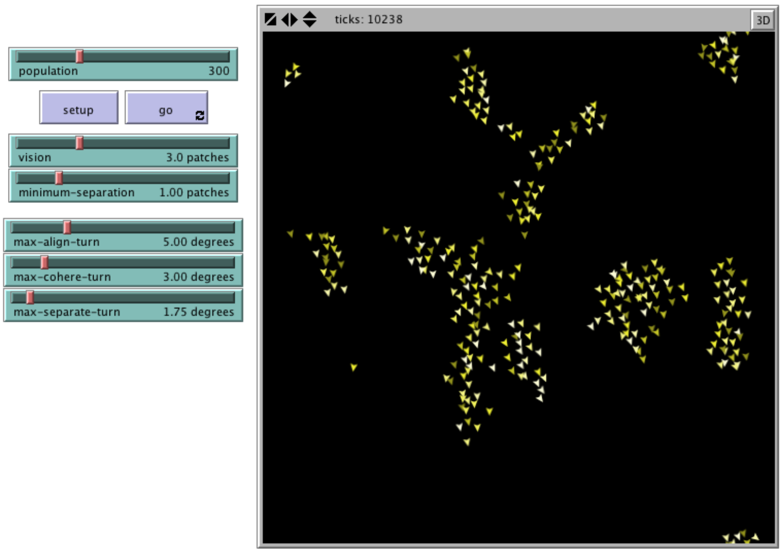
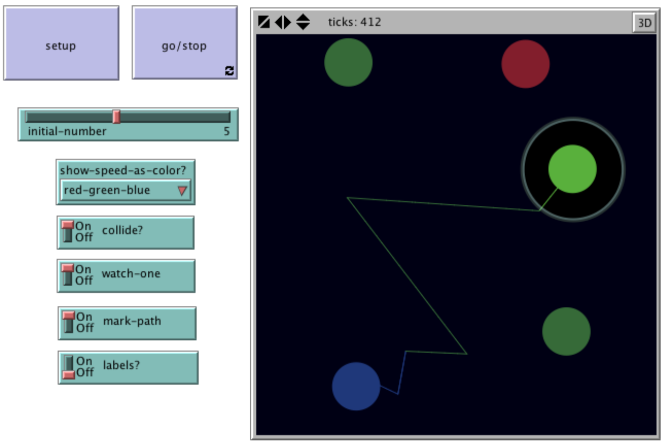
Appendix

Models used in the study

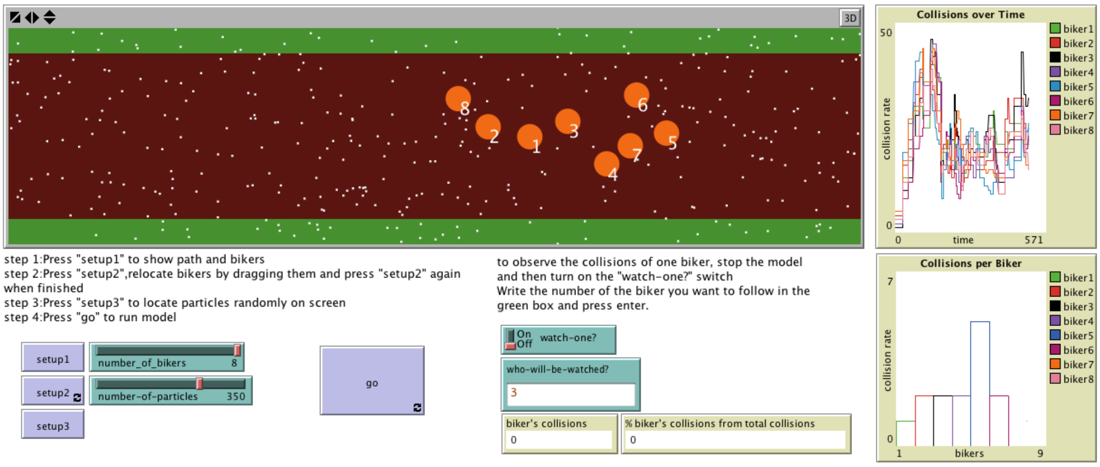


1. Flocking (Wilensky, 1998).



2. Adaptation of the “Connected Chemistry 3 Circular Particles” model (Wilensky, 2005).

3. Birds and particles: adaptation of the flocking model above, to include air particles and their interactions (Hirsh, Haviv-Gal & Levy, 2011).



4. Of particles and bikers: bikers (orange circles) move from left to right. One can adjust several features in the model, and most importantly change the spatial configuration of the bikers. On the right, one can observe the rate at which each biker is getting hit by particles, and how this changes over time. This rate is related to the effort expended by the moving through the air.

Computer as Chalk: Supporting Youth as Designers of Tangible User Interfaces

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Abstract

This report covers an effort to develop engaging technological tools and activities that promote learning and creative expression. It argues that the ways in which people use chalk can serve as an inspiration for rethinking how people can harness the expressive power of computational technologies. The report introduces the Hook-ups System, a set of technologies and activities designed to enable young people to create interactive experiences by programming connections between physical and digital media. With it, young people integrate sensors with various materials to create tangible interfaces for controlling images and sounds in computer programs. Research questions explored in an evolving design experiment probed how attributes of the Hook-ups System enabled youth from two after-school technology centers to engage in building personally meaningful projects, express themselves, and transform how they approached design.

Keywords

Scratch, sensor board, informal learning environment, physical computing, tangible interface

Introduction

The ways in which people use chalk (e.g., drawing hopscotch grids) can serve as an inspiration for rethinking how people can harness the expressive power of computational technologies. Today's computing devices have the potential to enhance expressive activities for diverse groups in similar ways that chalk does, but that potential has yet to be realized. This paper introduces a system designed to help young people explore chalk-like properties of computing technology. Now, more than ever, computers (and related embedded devices) need to fulfill their role of being machines that offer many avenues for dynamically creating artifacts.

Chalk has become a mainstay for far-reaching realms of work and play. In the form of sidewalk chalk, it allows children to lay a foundation for playing on any open asphalt or concrete surface (e.g., hopscotch and foursquare grids are often drawn in chalk). In the form of tailor chalk, it enables fashion-focused professionals and hobbyists to mark designs on a variety of materials that will be cut to create custom clothing. Sculptors even shape lumps of chalk into artistic pieces. Chalk can be the cornerstone for many creative activities for people with a variety of interests.

Too many citizens and children do not conceive of computers as being integral tools for the activities they engage in based upon their interests. It is common for computers that schools or technology centers make available to children to have software like adult-centered productivity tools, edutainment applications, and games. Applications that support creative expression are less common. Computers have made their way into many modern classrooms, but are typically used as a supplement to a typical classroom's information transmission culture. Chalk activities are established among a diversity of children as being more than a means of transmitting information from teachers to students. Seeing chalk peppering city sidewalks should serve as reminders of how children use the medium creatively and also serve as a challenge to creators of computational tools to strive toward making computers as much a part of children's creative culture as chalk is today.

This report provides insights into how children learn as they design using the Hook-ups System. The Hook-ups System is an attempt to transform computers into a new kind of tool for helping novices make interactive experiences – ones that encourage youth to learn in new ways through creating their own tangible user interfaces. The Hook-ups System is a set of technologies and activities designed to enable young people to program connections between physical and digital media, specifically by integrating sensors with various materials to create tangible interfaces for controlling images and sounds in computer programs that they themselves create. For example, a 10-year-old created a paper-plate-based flying saucer, added a sensor, then wrote a program to control an animated flying saucer image on the computer screen.

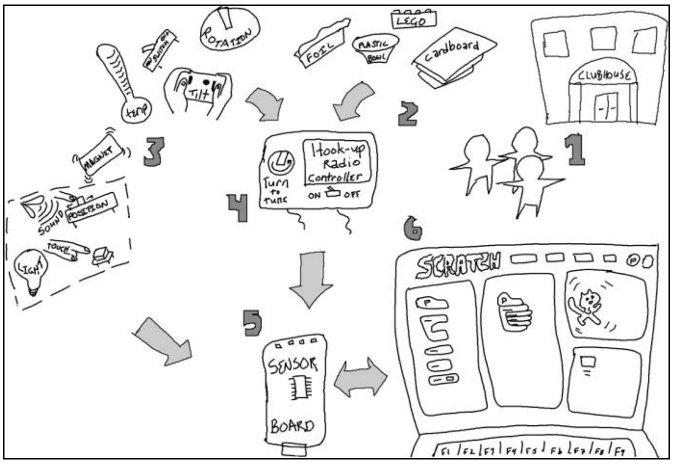

Figure 1. Elements of the Hook-ups System

Youth currently use Hook-ups tools for a range of activities that relate to their varied interests. It enables youth to act as "physical computing" designers – creating interactive experiences using the process sketched in Figure 1, which serves as an overview of how the elements that comprise the Hook-ups System work together. People usually over the age of seven [Figure 1-1] combine physical materials [Figure 1-2] with hand-made or manufactured components that react to changes in the physical environment (sensors) such as sound or light levels [Figure 1-3] to make a creation called a "Hook-up" [Figure 1-4]. People connect sensors (e.g., knobs or switches) on Hook-ups to the core technology of the Hook-ups System - Scratch Sensor Boards (Millner, 2007) [Figure 1-5]. This board plugs into a computer running a programming environment called Scratch (Resnick et. al, 2009) [Figure 1-6]. Scratch controls digital media according to how a person writes a computer program to behave when a Scratch Sensor Board notifies Scratch that part of the physical world that it is sensing has changed. The process of creating a Hook-up varies from person to person based on interests, experience, and materials available. Technical information about the Scratch Sensor Board (SSB) can be found at (Millner, 2007). Most of the 10,000+ sensor boards currently in circulation cost learners and educators $50 United States dollars to purchase (for the physical parts from sparkfun.com – additional shipping and handling costs varied).

Background

Constructionism is the cornerstone approach to learning upon which Hook-ups research is built. The approach suggests that young people learn best through the process of constructing artifacts that are meaningful to themselves or others in their communities. Papert argued that people learn particularly well while actively engaging in constructing artifacts to share with and be critiqued by others (Papert, 1980). Hook-ups work involves young people designing and sharing artifacts in community settings. Rogoff's idea of a community of learners (1994) suggested that learning comes as people participate in shared endeavors – transforming roles they play and understandings they have along the way. Creating Hook-ups in group settings typically involves transforming participation. Creators are idea generators at one point and collaborative problem solvers at others. Constructionist and community of learners paradigms both promote children having responsibility and autonomy as they relate to information as it is used in practices that are relevant to their community.

The progeny of the Logo programming language (McNerney, 2004) developed over the last 30 years serve as a foundation for the Hook-ups System. The trajectory of physical computing toolkits focused on making "tangible interfaces" to graphical programs running on computers are are also foundational. Toolkits described in an IEEE summary paper (Cottam & Wray, 2009) vary in intended use and audience, from MIDI-based toolkits for digital music enthusiasts to the BASIC Stamp for roboticists. Notably, the authors mention that essentially none of the toolkits in the tangible user interface space are designed to appeal to young learners. The Hook-ups System addresses that void in the up-and-coming physical computing field. It does so by providing an example youth-friendly system that features: a programming languages that is more visual than text-based; an interface board that reports sensor readings to a computer that is running programs that respond to interface board communications.

Other projects that relate closely to the chalk inspiration of the Hook-ups System are ones that situate computing within artistic contexts. Researchers are increasingly recognizing that establishing connections between computing and communities of other practitioners who construct physical artifacts has value for broadening who participates in computing. A growing number of designers of computational toolkits who believe that creative makers who work with traditional media such as paint can learn a lot from and change the thinking of fellow creative makers who work mostly with computation. For example, Graham's *Hackers vs. Painters* (2004) delineates ways in which painters and computer-savvy makers can benefit from adopting processes associated with learning both practices. Graham noted "I've found the best sources of ideas are not the other fields that have 'computer' in their names, but the other fields inhabited by makers. Painting has been a much richer source of ideas than the theory of computation."

Methods

The design experiment framework has guided Hook-ups research. Design experiments can be characterized as research projects that seek to achieve some practical change through iteratively re-designing educational spaces and to assess the successes and failures of the efforts on an ongoing basis (Brown, 1992). They provide a framework for engineering, re-engineering, and adapting to local conditions of innovative learning environments. These studies are oftentimes situated within complex learning environments. Using the framework helped highlight ways in which Hook-ups technologies and activities influenced the participants learning in two informal environments. Insights from the first case study below helped improve the tools and learning environment of the second case study.

Research questions focused on how the Hook-ups System exhibited attributes that enabled young people to create in ways that gave them experiences similar to those that people have when using chalk – engaging, expressive, and transformative experiences. The engaging attributes of chalk experiences help engage groups of young people who vary in culture, interests, and extracurricular activities. (E.g., chalk can mark up sidewalks for hopscotch). The expressive attributes support youth in creating and sharing projects that express parts of their personalities, passions or positions on social issues. (E.g., chalk can be sculpted into artistic expressions.) The transformative attributes transform how youth approach design – enabling them to explore design strategies and engineering ideas. (E.g., iteration is easy with chalk.) The questions asked:

In what ways does the Hook-ups System:

- Q1) engage groups of young people who vary in culture, interests, and extracurricular activities within an informal learning environment;
- Q2) support youth in creating and sharing projects that express parts of their personalities, passions or positions on social issues; and
- Q3) transform how young people approach design – enabling them to explore design strategies and engineering ideas?

This study's research questions examined the extent to which the Hook-ups System has been designed and deployed in two informal learning environments in ways that made it embody the attributes of chalk by being: adept at *engaging* a diversity of youth interests in creative processes, capable of evoking self-*expression* during creative processes, and instrumental to activities that helped children *transform* their approaches to design.

The Hook-ups design experiment structured how data were collected and analysed about how the people in the learning environments adopted the System. Multiple data streams from a set of visits to one site would inform the plans for future visits to that site and the other research site. The data also guided iterative refinements to the Hook-ups System. Data included field notes, project artifacts, video recordings, and surveys. Primary findings are presented as case studies.

The Hook-ups System: Case Studies & Analysis

Two cases are presented to show Hook-ups in action: Stuffed Bears and Hot Potatoes. Each case presents the accounts of events, artifacts, and experiences that indicated that the Hook-ups System enabled learners to have experiences that were engaging, expressive, and transformative.

Stuffed Bears

A group of teens taught two stuffed bears how to "talk" at the South End Technology Center (SETC). SETC is situated within a set of housing developments. Its population is comprised of mixed-generation learners - people from the ages of four to "no-longer-counting." The Center offers: free computer access to youth of all ages; computer-controlled fabrication devices such as laser cutters; craft materials; a soldering/circuit-making workbench; and a program called Learn 2 Teach, Teach 2 Learn (L2TT2L).

L2TT2L mobilizes teens in their out-of-school time to gain knowledge in emerging technical domains, to create their own ways to share knowledge with their younger peers, and to contribute to the leading edge of technological innovation. It is an evolving multi-part program that provides an opportunity for youth (aged eight and up) to engage in projects related to science, technology, engineering, and math as they might in some college environments. Once teens are hired into the program, they are paid a salary to be teachers of their peers. During a summer phase of the L2TT2L program, participants use part of their time working on group projects (when they are not teaching younger learners community centers). One participant of the 2007 summer session, Shawn, discussed his experience creating the Stuffed Bears Hook-up in response to a survey question asking him to explain his three-month long summer group project.

> Shawn: The first year of my L2TT2L journey, I was grouped with about 6 or 7 young people. Our community-based project was to create a robot that struck out to gang violence or whatever violence struck in our community. So my project was a talking bear […] We took a regular bear that kids probably 7 or 6 play with and we inserted sensors in the bear - in the hands, the feet, the stomach, and I think we had some in the ears too. We recorded sounds into the sensors so if one of the kids pressed the palm of the bear, it would either say a phrase or teach […] The songs would be either teaching the kids how to recite their ABC's, their 123's, or just have positive messages. In our communities, there's a lot of gang violence so we wanted to start by creating a project that would affect the kids younger than us so they wouldn't have to live through the same.

The idea for Shawn's project came when one of his six project group members brought an old electronic stuffed bear toy to SETC. The toy, named Talking Bubba Bear, was dressed up in overalls and a flannel shirt – an outfit inspired by farmers. It said things with a southern U.S. accent when someone squeezed its paw. For example, one squeeze would play one of the 200 phrases it had in its memory such as "hey, will you fluff up my hair? Come on, wiggle my head and fluff up my hair." When a person wiggled its head, it would then respond by laughing. That bear became the base upon which Shawn's group built its summer project: Thugaboo and Proper Bear (Figure 2). The project group members realized that toy companies used technology to make caricatures of certain dialects, such as southern U.S. accents. Why shouldn't they try making their own caricature toy? No one in the group knew of any toys that spoke like some of the thugs in their neighborhoods. They figured that they should make their own – or at least, modify the existing toy to say things that they wanted it to. They called their first modified bear Thugaboo.

Figure 2.The Proper Bear and Thugaboo Hook-ups

Shawn’s group was looking to learn about how the existing electronics worked inside of the talking bear so that they could know where to modify it. The group also sought help from the three adult L2TT2L staff members as they attempted to understand how the toy's sensors were connected. Group members explained their attempts to understand the bear's sensors to staff. Instead of guiding the group to use multimeters to measure signals, staff helped group members probe the bear's wires by having the participants touch wires with alligator clip-heads that measure resistance from one of four ports on a Scratch Sensor Board. The group put clip-heads on two wires and watched the Scratch screen as they squeezed different parts of the bear. On the screen, they had a read-out showing the status of whether sensor-A was connected. It would toggle from "FALSE" to "TRUE" when a person squeezed the part of the bear that contained the sensor to which the Scratch Sensor Board alligator clip-heads were attached. The group labelled the wires to keep track of sensor mappings so that they could write programs specific for each.

Shawn’s group played around with messages from the Thugaboo bear that sounded like they were coming from a seasoned neighborhood thug. For example, one recording urged kids to "learn your ABCs" instead of "getting A's and K's." The latter was referring to something that kids might do if they involved themselves in the gun-violence-ridden world associated with becoming a thug. The "A" and the "K" alluded to the first letters of infamous AK47 assault rifles. Thugaboo spoke using a vocabulary with which Shawn's group felt their target audience would be familiar enough to understand and find funny.

The group used what it learned from converting Bubba Bear into a Hook-up to design a second bear that also delivered stay-in-school messages. They made this bear, which they called Proper Bear, use a vocabulary that they did not associate with thugs. Instead, they recorded phrases in what they called "proper" English. They started with a stuffed bear that came with no built-in sensors. They instrumented it with switches that were small enough for them to maneuver through the stuffing into the bear's extremities. They mapped some of the recordings in a Scratch project to the sensors in Proper Bear. They dedicated four alligator clip-heads of a Scratch Sensor Board to Thugaboo and another four to Proper Bear for a demonstration at the 2007 L2TT2L final project exhibition (that was open to the public). They used one Scratch program that had a drawing of a bear on the screen to show users where the bears' squeezable sensors were. The program included multiple recordings for each bear and would play different quotes at different times. The idea was that all types of people (and toys in this case) could speak to children about the importance of educating themselves. The bigger idea was that promoting education would deter young people from making decisions that lead to gun violence.

Hot Potatoes

The Hot Potatoes Hook-up resulted from three weeks of work in the Charlestown Computer Clubhouse. Computer Clubhouses (Kafai, Peppler, & Chapman) are centers that offer low-income communities an array of computer technology outfitted with a professional suite of design software. Most of the roughly 100 Clubhouses distributed across 20 countries are over 1,000 square feet spaces that incorporate a large community table, clusters of computers, and studios for music recording and video recording/editing areas. The Charlestown Computer Clubhouse is located in a Boys and Girls Club facility, where the Clubhouse is one of many activities club members have to choose from during after-school hours (up to 8:00 PM). Any member of the Boys and Girls Club was welcome to join Hook-ups drop-in activities that took place from the hours of 4 – 7PM once a week during the winter months of 2010. The participants in this case used an improved Scratch Sensor Board released after the concluding the sessions in which the Stuffed Bears were created. The Hot Potatoes creators could get started on their work earlier in the workshop because the improved Scratch Sensor Board’s USB port and auto-detecting software required less configuration to get up and running than the Stuffed Bears team had to do each session.

The Hot Potatoes project started when a small group of five Clubhouse members (aged 13-16) came together to learn how to make interactive experiences that called for full-body interactions, similar to Nintendo Wii games. They wanted to know how a Scratch Sensor Board could be used to make Scratch projects that involved movements like a person swatting a fly. The group thought of fun interactions that involve people’s hands and the idea of hot potato came up. Hot potato is a game that emerges when a group of people start throwing any small object from one person to another - each one trying to throw the object to someone else as fast as possible, like a hot potato that will burn him or her if it is held for too long. After figuring out that hot potato was a game that constantly called for an object going from a well-lit area (such as open air) to a dark area (such as inside of a pair of hands), one member of the group draped a brown paper bag over the Scratch Sensor Board to make it look like a potato. Another member made sure to cut a hole in the bag where the Board's built-in light sensor was positioned so that they could use light feedback from that sensor in a Scratch program.

The initial Hot Potatoes project involved a drawing of a hand on the Scratch screen holding a potato when a person was holding the physical "potato." It worked, but the group wanted a game that was more playable than carefully tossing around a tethered "potato." They realized that it would not be a good idea to perform a high arching throw as doing so might disconnect the Scratch Sensor Board or worse – make the laptop fall. The group had to make a potato that they could throw around freely in a way that Scratch could keep track of it.

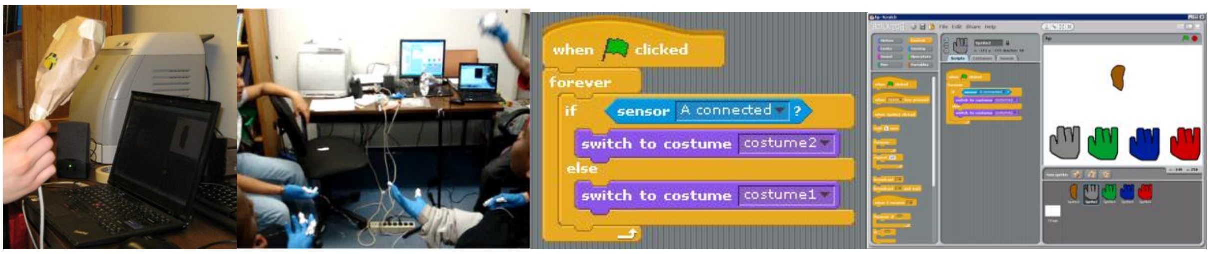

Figure 3.The Hot Potatoes Hook-up

The group covered a tennis ball with foil. Group members made gloves that connected their thumbs to one alligator clip-head on a Scratch Sensor Board and their index fingers to the other clip-head. One person's hand was wired to a Scratch Sensor Board's "A" jack. Other people's hands were connected to jacks B,C and D. The group made the project (in Figure 3) show which player was holding the potato by drawing two costumes/images for each of four hands – one holding a potato, and one without. The group tested the code that determined which hand on the screen should show that it was holding the potato – according to who actually held the "potato" at the time. While four people wearing hot potato Hook-up gloves tossed the "potato" to test the code, the fifth person sat at the computer and drove the programming.

Although the initial code functioned, it did not account for a representation for the potato when it was in the air – and not in a person's hand. To make a potato image appear in the air at the right time, a member named Kendi had to be very specific as he described the condition in which he wanted the on-screen potato to appear in the virtual air. Kendi thought out loud about how he could get past what he perceived to be a bug in the program. One of his colleagues, suggested that Kendi make several scripts to handle each case – one to announce when the potato was not in player A's hand and similar scripts for players B,C, and D. Instead, Kendi opted to make his own script. He figured out that he could make one command block test multiple conditions: if the potato was in player A's hand OR player B's hand OR player C's hand OR player D's hand. If any of those conditions became true when his program ran, the script would make the image of the flying potato hide. After his peers tested his code, Kendi was elated when he looked back to the computer screen to see that the flying potato image appeared when the physical potato was in flight. He raised both hands and exclaimed, "I'm a genius!"

The group had to debug/solve additional issues that arose both in the physical and virtual worlds. For example, they had to fix short circuits that would happen when players moved their bodies too much and caused the wires that connected a glove to the Scratch Sensor Board to cross. The group had been using wire that had no plastic coating to prevent two wires from completing a circuit when they came into contact with one another. Having no other wires available, the group continued to play, but discovered that their jeans were good insulators – so they kept wires on each side of their legs.

Analyzing elements of Hook-ups System experiences across cases

The Hook-ups System helped the Stuffed Bears and Hot Potatoes creators gain experience in designing interactive systems and learning engineering design practices in a group setting.

Supports for engaging experiences

A key quality that made engaging experiences possible was the Hook-ups System's ability to connect with participants' personally meaningful activities. The Thugaboo and Proper Bear Hook-ups engaged the six-person group (and peers around them) who shared an interest in making up voices to caricature certain lifestyles (thugs or over-articulate people). This case highlights that Hook-ups helps give teens new experiences that leverage interests they had as young children – pretend play with stuffed animals – and adds new dimensions for exploration.

Hot potato is the kind of game invites people of all ages to join in. The Hook-ups System helped turn a competitive (yet friendly) activity into a collaborative building experience. Basing a Hook-up on hot potato tapped into the kind of quick and fun group interaction which the participants found engaging in Wii games they played. One technical feature of the Hook-ups System that helped the group make Hot Potato was the four external sensor jacks. In the case of Hot Potatoes, one switch on each jack could represent a separate player. Four jacks enabled four players to engage in tossing a potato around comfortably. The group managed informal turn-taking as they balanced playing, iterating their game's design, and debugging.

Supports for expressive experiences

A key quality that made expressive experiences possible was the System's ability to connect to participants' personally meaningful materials. The Thugaboo Hook-up represented an especially expressive project. One of its creators sparked the project idea by bringing an old toy to work. The Scratch Sensor Board's ability to connect to the existing sensors in his toy – a talking stuffed bear - made the project very personal. The playing-card size of the Scratch Sensor Board was conducive to embedding it inside of the bear so that people were interacting with the bear instead of the Board. The bear Hook-ups were also expressions of multiple issues that the creators sought to address. The Hook-ups System helped them find their own way to promote education as a way to mitigate the growing problem of gun violence in their communities. The content of what the group programmed the two bears to say was in and of itself expressing a lot. Both bears were giving stay-in-school messages using different delivery styles. The creators were expressing that positive messages are received differently when delivered by someone people are familiar with.

The Hot Potatoes Hook-up creators used the project to playfully express how they felt about one another. One of the participants wanted to project how different he was from his peers by making an unusual art request for the hand graphic on the screen that mapped to his glove. He told his friend who was drawing the on-screen images to draw a square-shaped potato in *his* hand instead of the oval potato that the artist was drawing for the other players. That is, the requester wished to stand out by having a square potato graphic appear in his hand every time he caught the actual potato. His friend who was drawing the graphic granted his request for individual expression.

Supports for transformative experiences

A key quality that made transformative experiences possible was the System's ability to encourage and support iterative design processes. Before Shawn's group could create Thugaboo, they had to figure out how to repurpose Talkin' Bubba Bear. Group members were each taking a new approach to design – breaking down something old to make something new. To break down Bubba Bear in a way that preserved parts they needed, the group had to test whether components inside the original toy were trash or treasure for them. As they disassembled the toy, they were able to think about which of the sensors in various body parts they wanted to take over. For example, when they noticed that Bubba Bear reacted to stomach squeezes, they thought about more statements that Thugaboo could say – realizing that they weren't limited to sensors in his extremities.

The Hot Potatoes Hook-up represented an especially transformative project. Its creators changed both the scripts that governed their game and the physical components of the Hot Potatoes interaction while their peers were playing. Doing so allowed the participants to constantly have live feedback for the changes they were making and enabled them to try new project directions quickly and iteratively. When transforming an approach to design, the style with which one builds and the attitude taken while doing so evolves. The Hot Potatoes group took the approach of learning on-the-fly as they extended their prototype rapidly and dealing with interaction issues as they arose. In the spirit of getting a Hot Potatoes prototype running quickly, no one in the group noticed that the hands of each participant were wired using exposed-metal wire instead of plastic-covered/shielded wires. This oversight helped the group learn about electrical conductivity. As the group debugged the short-circuit issue, they discovered ways in which wires in an electrical circuit could be connected or interrupted.

Conclusions and Contributions

The Hook-ups work was successful across the different workshop settings that each case represented. The Stuffed Bears case was opt-in work as a part of a three-month program. The Hot Potatoes case was a drop-in effort over the course of three weeks. Nevertheless, both showed that the Hook-ups System was adept at *engaging* a diversity of youth interests in creative processes, capable of evoking self-*expression* during creative processes, and instrumental to activities that helped children *transform* their approaches to design.

This Hook-ups research contributed technological tools that promote learning and creative expression. Using chalk as an inspiration while designing the Hook-ups System contributed to youth becoming engaged in building tangible interfaces and helped people rethink how they can harness the expressive power of computational technologies. This work can serve as an example for designers interested in making new platforms for enabling young creators to extend activities they're involved with, incorporate a multitude of materials around them into projects, and evolve their design skills as they iteratively improve projects.

Acknowledgements

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Three-minute Constructionist Experiences

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Abstract

Constructionist learning experiences typically take time: time to build and run programs – typically even more time to learn how to program. As authors of constructionist tools and learning designs we faced the challenge of giving visitors to the Royal Society Summer Science Exhibition an authentic constructionist experience when most visitors were expected to stay only a few minutes. Furthermore we needed to help the visitors learn something about the subject matter of the exhibit – the spread of viruses.

To meet these challenges we built and exhibited the Epidemic Game Maker (http://m.modelling4all.org/p/en/sse.html). The Epidemic Game Maker starts with a bare-bones model of an epidemic. Users can enhance the model and add game play elements. Rather than exposing them to the complexity and full power of the Behaviour Composer (Kahn & Noble 2010) or NetLogo (Wilensky & Rand in press), we built a simplified interface customised for building games and models of epidemics on top of the Behaviour Composer. Interactions are limited to toggling twenty check boxes. Each check box replays a different sequence of changes to the model that we pre-recorded. For the adventurous user who wishes to go deeper with a few clicks the full interface can be exposed where they can explore and alter the agents, behaviours, and underlying code that constitute their model. The generated games can be based upon a model significantly richer than the initial model. Game play can be introduced by adding buttons to enact public health authority actions. All of this is done on a single page in a web browser – an interface that visitors are already familiar with.

Here we report on the design of the Epidemic Game Maker and our impressions of the more than one thousand visitors who created games during the exhibition.

Keywords

Agent-based modelling, Behaviour Composer, NetLogo, Epidemic Game Maker

The Epidemic Game Maker

We designed the Epidemic Game Maker (EGM) so that users with no computer programming knowledge, little computer experience, and the bare minimum knowledge about how infections spread can

- construct and run epidemic models in a minute or two
- construct and play increasingly complex epidemic games in five to fifteen minutes
- construct games that help them learn about the dynamics of epidemics and the trade-offs of different public health interventions
- can continue to play and share their games at home or school
- learn about computer modelling
- have fun

To address the first requirement we provide a ready-made model that consists of a population of students who travel daily from home to school and back. Initially one student is infected. When an infected person is at the same location as a susceptible person then with specified odds the infection is transmitted. People recover from infections after a specified amount of time. This is based upon the standard susceptible-infected-recovered model of epidemics (Scherer & McLean 2002). The opening screen encourages them to run the model.

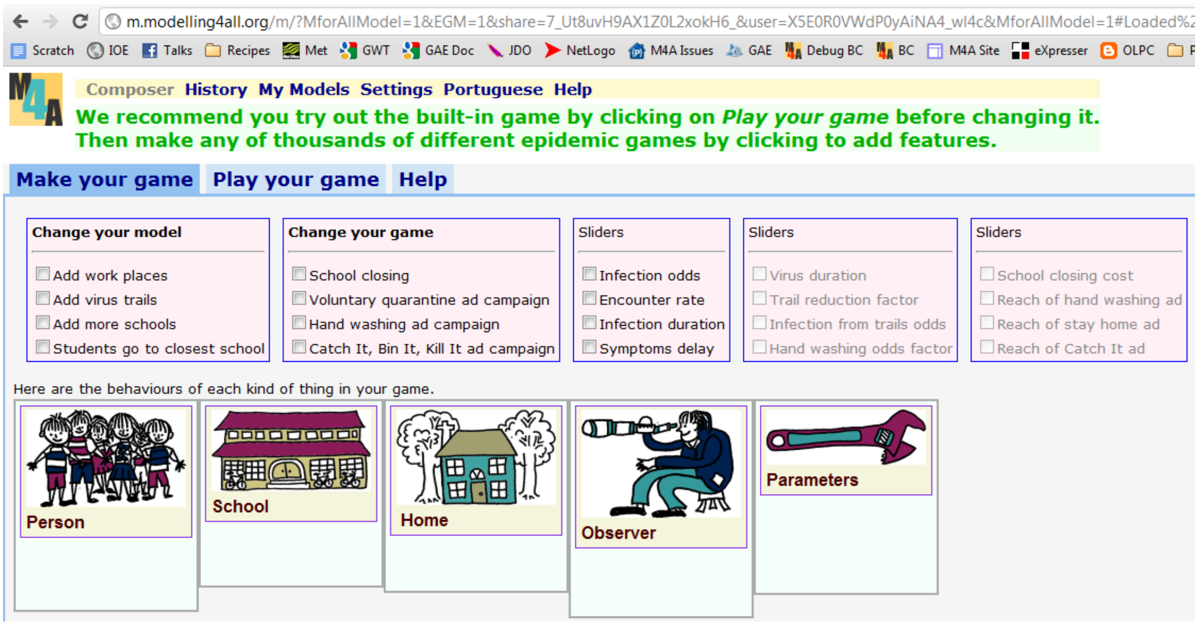

Figure 1 – Initial 'home page' of the Epidemic Game Maker

(the check boxes are explained below)

After clicking on the 'Play your game' tab, the Java applet for the game is loaded into the user's browser.

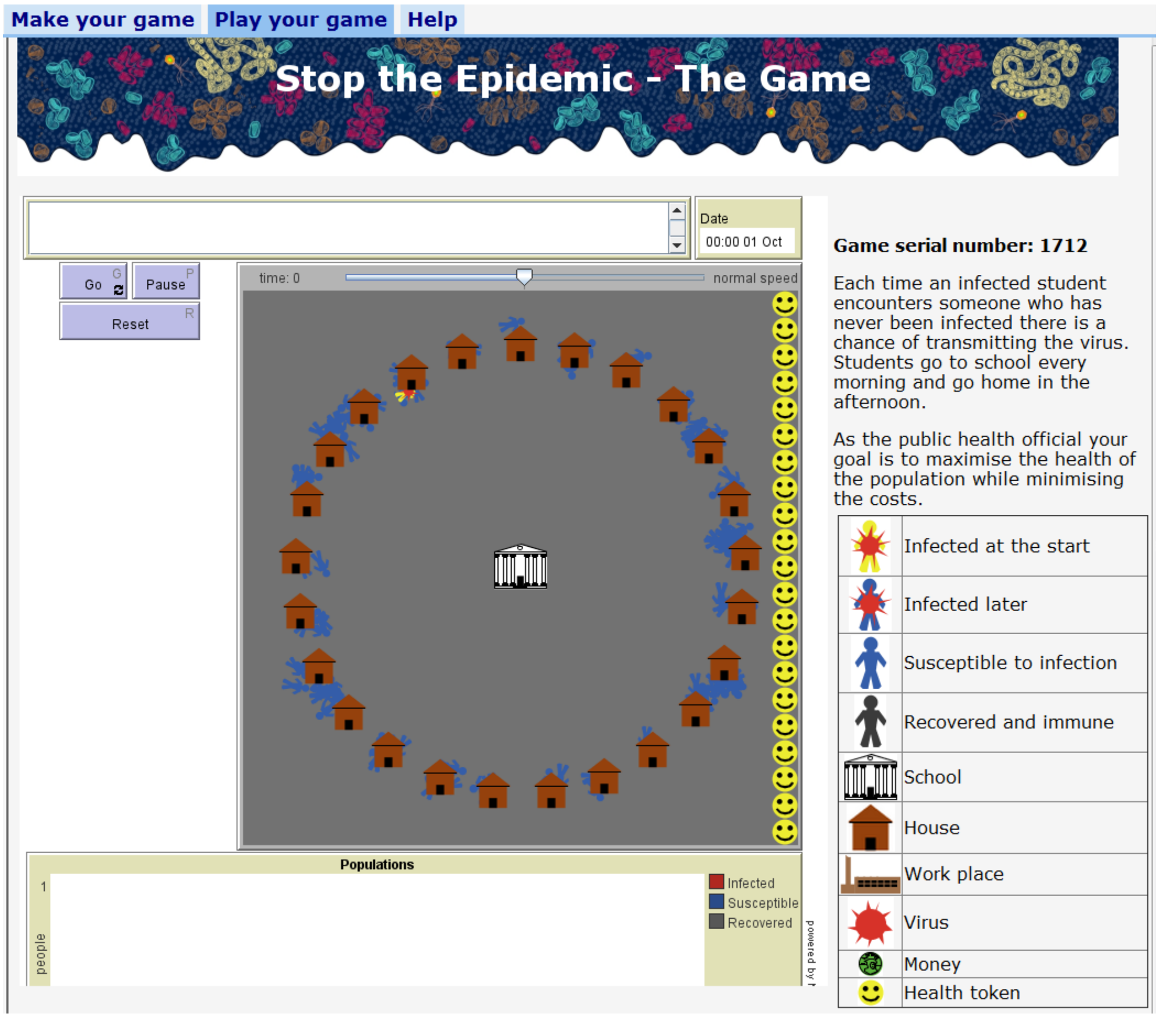

Figure 2 - Initial base game screen

There are two kinds of simulation games: (1) simulations where the player or players are among the individuals being simulated (e.g. controlling a fish that is part of a simulated school of fish) and (2) simulations where the player has global control (often called 'god games'). The EGM can be used to make pure models or models with game elements. With minimal settings the EGM makes a simple epidemic model that lacks game play elements. At the top of the interface there is an area for messages and a display of the simulated time. Buttons are available to run, pause, or reset the simulation. The world is portrayed as a circle of houses with a school in the centre. Students are at home and one is infected (in Figure 2 the infected student is at approximately 11 o'clock). The smiley faces act as a health gauge. At the bottom graphs of the infected, susceptible, and recovered populations are drawn.

The model can be run multiple times and due to the stochastic nature of the transmission of infections each run is different.

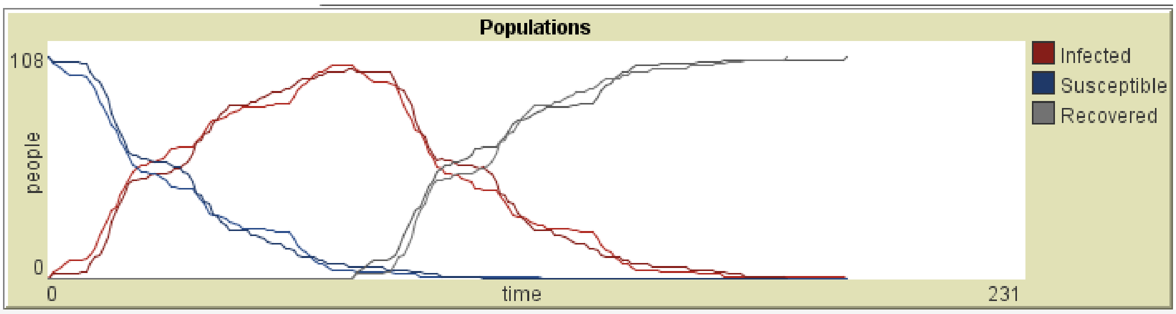

Figure 3 - A typical graph showing two runs

The constructionist aspect of the Epidemic Game Maker is supported by tick boxes that add or remove model and game enhancements as well as fine control over parameters. The model changes supported are

- **Add work places** – Introduces adults that regularly commute to work
- **Add virus trails** – Viruses that can infect people are left behind by infected people
- **Add more schools** – Adds three more schools
- **Students go to closest school** – Students go to the school closest to their home

Users can explore and discover interesting interactions between these enhancements. Adding more schools and requiring that students go to the local school limits the epidemic to a single school. Introducing adults then provides a means for an infection to jump from school to school (by a student infecting a parent at home who infects a co-worker from another neighbourhood who infects one of their children). This pattern is similar to how a disease can spread between countries via air travellers.

Users can also add buttons to introduce game elements that enable players to try to stop the epidemic. The supported enhancements are

- **School closing** – When schools are closed students stay home. Keeping schools closed has societal costs and they will be automatically re-opened if funds run out.
- **Voluntary quarantine ad campaign** – Every button click reaches a specified proportion of the population to stay home once they are aware that they are infected.
- **Hand washing ad campaign** - Every button click reaches a specified proportion of the population causing them to wash their hands frequently thereby reducing the odds of acquiring the infection from viruses left behind.
- **Catch It, Bin It, Kill It ad campaign** - Every button click reaches a specified proportion of the population to use tissues to reduce the trail of viruses they leave behind.

Each run of an ad reduces the remaining budget. The latter two only make sense if '**Add virus trails**' has been added to the model. All of these enhancements can spark good discussions. Does school closing really cause children to stay home? What if the model was enhanced with shopping centres where the students might go when school is closed? A '**Hand washing ad campaign'** encourages people to act in their own best self-interest to reduce their odds becoming ill while the '**Catch It, Bin It, Kill It ad campaign**' encourages people to stop harming others.

The effects of all of these enhancements depend upon the values of model parameters. Users can choose to add sliders to explore the consequences of different values. The sliders they can add are

- Infection odds

- Encounter rate
- Infection duration
- Symptoms delay
- Virus duration
- Trail reduction factor
- Infection from trails odds
- Hand washing odds factor
- School closing cost
- Reach of hand washing ad
- Reach of stay home ad
- Reach of Catch It, Bin It, Kill It ad

To enable visitors to continue to play and enhance their game the EGM generates a four-digit serial number for each game. We gave each visitor a nicely printed card where they could write down their serial number. The card included the project URL (modelling4all.org) where they can enter their serial number to restore all of their settings.

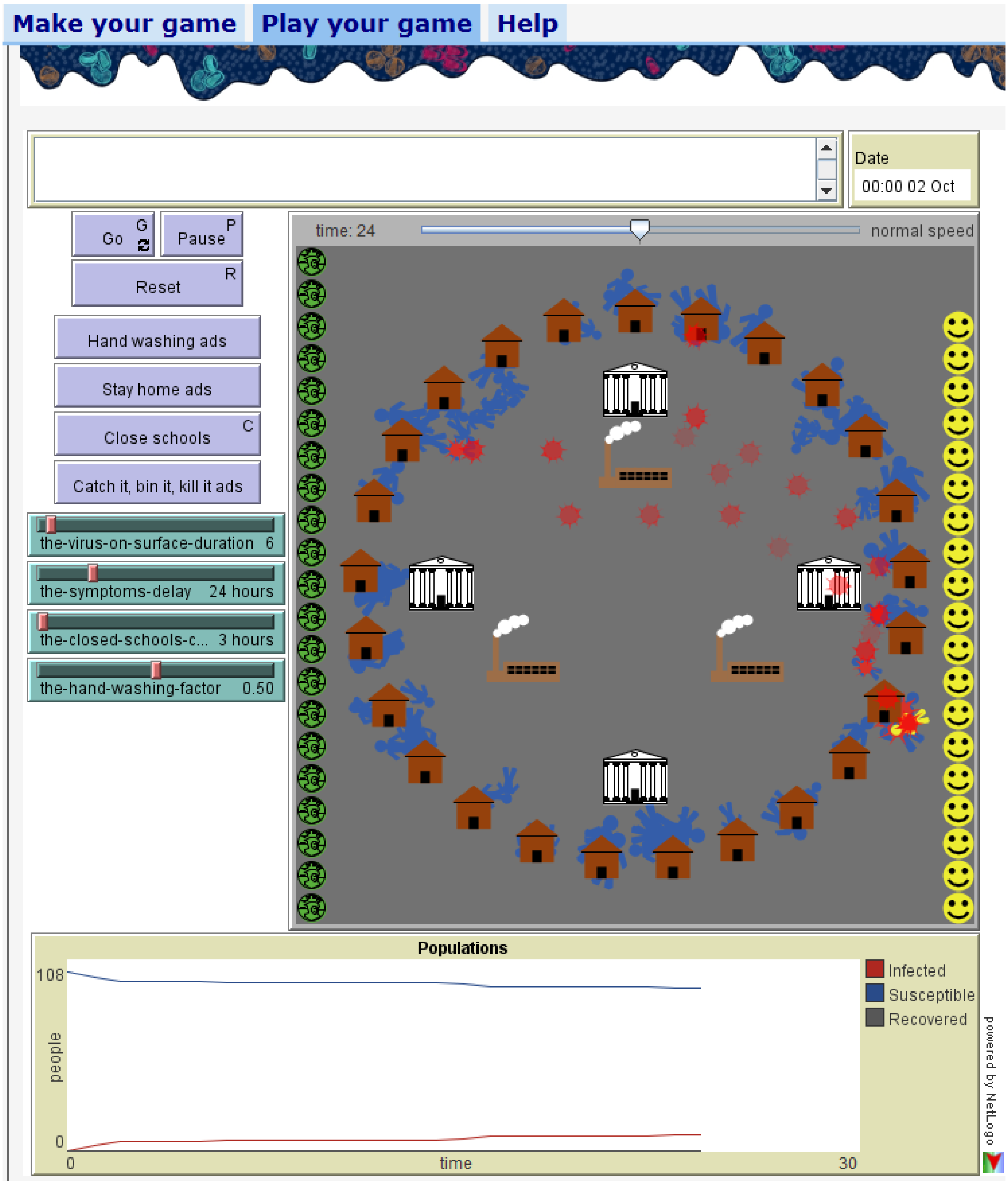

Figure 4 – A game with all enhancements and four sliders

The Royal Society Summer Science Exhibition

The Royal Society holds the United Kingdom's most prestigious science exhibition every summer. We participated in the 2010 event (http://seefurtherfestival.org/) which was expanded to celebrate the 350th anniversary of the Royal Society. Fifty thousand people visited the exhibition over ten days. This included almost two thousand registered students and 240 teachers. 1750 VIPs (including the Queen of England) came to a closed showing. The EGM was part of the exhibit on 'Emerging infections: viruses that come in from the wild' (http://seefurtherfestival.org/exhibition/view/emerging-infections-viruses-come-wild).

The main aim of the Royal Society event was to provide the general public with an opportunity to speak to real scientists about their field of research. We were asked to focus primarily on 12-16 year olds but to expect people of all ages. The EGM allowed us to discuss both the factors that determine the spread of a virus and how computer models might contribute to our understanding.

Experiences of a thousand visitors ranging from young children to fellows of the Royal Society

During the exhibit over 1100 games were created using the EGM by approximately a thousand visitors (many games were made by small groups). In the two weeks following the exhibition 200 games were made by on-line visitors. It was noticeable that people varied in terms of how willing they were to experiment with the model as opposed to discuss epidemics with members of the Oxford team hosting the stand. As the exhibition continued we arrived at ways to structure conversation so that:

- Those who were quick to centre their attention on experimenting with the EGM could be encouraged to generate ideas for improving the model
- Those who preferred to discuss epidemics orally would turn to the EGM to test the assumptions they held in their head.

In both cases the art of conversation was to arrive at a point with each visitor gained a healthy level of scepticism about computer modelling i.e. they should neither treat the model as a black box for predicting the future, nor just as simply a toy that did not match the *common sense model they held in their head*.

In this way we tried to give each visitor the intuition that:

- Computer models of epidemics are useful because they augment our ability to think about systems that are too complex to think about in our heads alone.
- All models of epidemics are built by making very important assumptions about how people will behave in a given situation, and many assumptions they might think are important could have been left out for the sake of simplicity.

Some nice examples that we feel demonstrate a positive outcome from using the EGM:

- Many visitors were very quick to point out that in the middle of London it is very important to model how people move between home, work and school i.e. whether they walked, cycled, took the bus, tube or boat.
- Particularly teenage girls were quick to point out that any public health intervention that focussed on improved personal hygiene (washing hands) would be most effective if targeted at boys.
- Most teenagers who engaged with the model were adamant that a stay-at-home policy would never work – teenagers would instead congregate at someone’s house or a park. (They correctly pointed out that this would likely negate any gains from closing the school).
- Some young children (6-10 year-olds) built a series of games and demonstrated a clear understanding the model and the interventions. Younger children enjoyed playing with the game – a few played for more than ten minutes.
- Many people questioned the assumptions built into the model pertaining to the cost of closing schools and workplaces to the economy.
- A few learners asked to see the underlying code. One “improved” the model by adding one

> of the generic Behaviour Composer micro-behaviours “wander randomly” to a school. This caused the school to move around on the screen, and all its pupils to chase around after the school. While this is not directly related to learning about epidemiology, we felt it was an interesting example of a learner opening up the black box and seeing the model as something malleable that he could do with whatever he pleased.

Of course we would have loved to have spent more time with people to support them in building their own assumptions and ideas into an enhanced version of the EGM. In the few brief minutes we had with visitors we hope they were left with at least a latent desire to do so one day.

Theoretical underpinnings

We wanted the EGM to work as an object to think *with* for the learners when engaging with new knowledge of epidemics. It was important to us that the EGM would facilitate thinking and conversation about epidemics that learners could relate meaningfully to their own lived lives.

Epidemiological modelling is largely taught using variations of the SIR (Susceptible-Infected-Recovered) model, using sets of deterministic differential equations that predict the relationship between changes in the three categories of people. Because of the use of differential equations, the conventional SIR model requires a high level of knowledge of calculus, and is typically not taught until the undergraduate level. However, using Agent Based Modelling as a restructuration (Wilensky & Papert, 2010), we were able to meaningfully engage young learners in discussing and thinking about this complex issue.

(Wilensky & Resnick, 2006) argue that Agent Based Modelling can facilitate an ‘embodied modelling approach’ by asking learners to think like the agents they are modelling. By doing so they are able to break down the behaviours of agents into bits of code and generate computational theories about the relationships between them. We took this idea as a starting point for the design of the EGM. By focusing on the lives of our learners, the main question that we hoped to engage our learners in was, “Given this situation or policy or intervention, is this what *you* would do?” As we demonstrated above in the examples of learning with the EGM, those were exactly the questions that people asked of the EGM in order to both make sense of the model, and to offer informed critiques of it. For instance, in the example of the stay-at-home policy not being effective, the main critique offered by learners was that they would in fact not stay at home, but go and hang out with their friends. This critique was drawn from learners’ own lives, and illustrated to us that learners were able to engage with this complex issue in a deep and critical manner.

Finally, we wanted to engage learners in thinking about the relationships between their own and their family’s behaviours; the properties of the virus; the policies enacted; and the aggregate outcome of the epidemic model. (Wilensky & Resnick, 1999) argue for an ‘emergent view’ of levels in complex systems in which aggregate outcomes appear at ‘levels’ that emerge out of the complex interactions between agents. By allowing learners to add or remove complexities (number of schools, workplaces, virus trails, etc.) our hope was that learners would experience these emergent levels and see that what happens at the aggregate level in the model is not a hard coded, black box phenomenon, but simply the result of the complexities that learners added to the model.

Building other ‘Game Makers’ in the Behaviour Composer

The Epidemic Game Maker was implemented by building it on top of the Behaviour Composer.

This approach provides a smooth integration but requires a deep understanding of the implementation of the Behaviour Composer. Subsequently we have enhanced the Behaviour Composer so that an 'end user' could build something like the EGM without touching the source code of the Behaviour Composer.

To create a different game maker (or a model maker) one starts by creating the base game or model in the Behaviour Composer. From the 'share' tab one can obtain a URL that will load the model. One then authors and hosts an ordinary HTML web page. The model URL needs to be enhanced to include '&tab=…' where the URL to the web page is added. To add check boxes the page should contain the following text for each check box:

```
Begin Replay Session Events Check Box:
ID: a name for the check box
Label: the label associated with the check box
Session ID: a session ID described below
Do message: a message displayed when checked
Undo message: a message displayed when unchecked
Title: the title displayed when the mouse hovers over the check box
End Replay Session Events Check Box
```

Figure 5 – Mark up code needed to generate a session replay check box

When this page is loaded into the Behaviour Composer all this text is removed and replaced by a check box. The session ID of a check box is obtained by loading the base model into the Behaviour Composer and then making changes to the model. The system provides a session ID that can be used to recreate the changes performed. By copying and pasting the ID into the check box form the check box when ticked will replay all the changes and unticking it will remove the changes. The rest of the web page can provide background and instructions.

Conclusions

Although our experience with the EGM lasted for just some minutes with each participant we think that the game, together with the Behaviour Composer environment, open many possibilities to teachers and students to explore models and simulations in educational settings integrating different disciplines such as biology, mathematics and social science.

The Logo family of languages, including NetLogo and Scratch (Resnick et. al., 2009), aspire to have a low threshold so users can begin to build without a large upfront investment to acquire the prerequisite knowledge. However, in the context of an exhibit the threshold needs be a few seconds of instruction. For turtle programming there have been near-zero threshold implementations called 'Instant Logo' or 'single-key Logo' since the mid-1970s (Goldenberg, 1974; Solomon & Papert, 1975). In the same period Radia Perlman pioneered special hardware interfaces for pre-school children to program turtles (Morgado et. al., 2006).

Agent-based modelling is significantly more complex than turtle programming. NetLogo, for example, extends turtle programming with agents, agent sets, links, patches, and much more. The author of a game maker such the EGM will need much of this richness. The challenge is how to (temporarily) hide this complexity from users. The approach presented here is to provide a simple or partial model and to provide a user interface that automates the addition of several major model enhancements. Unlike 'Instant Logo' we are not providing the user with generic primitives upon which to build but instead high-level domain-specific components. We are attempting to support ‘middle-up’ programming rather than ‘bottom up’. The low level code (i.e., NetLogo) is available and accessible. Users are encouraged, but not required, to deal with it.

Program and source code availability

The EGM is freely available from http://m.modelling4all.org/p/en/sse.html. The Behaviour Composer is available from http://m.modelling4all.org. The source code is available at http://code.google.com/p/modelling4all/source/checkout.

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MultiMap: A Computational Environment for Supporting Mathematical Investigations

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Abstract

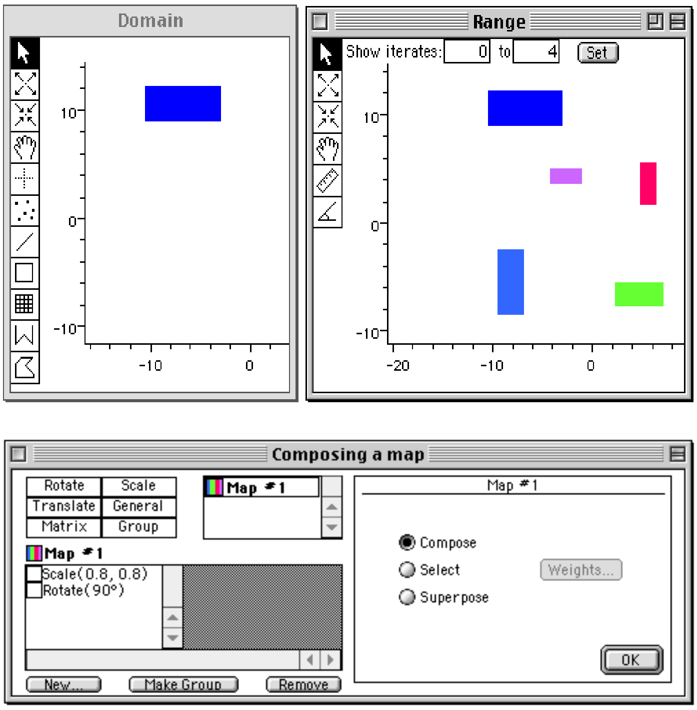
MultiMap is a visual computational environment expressly designed to support the learning and teaching of mathematics. The MultiMap software transforms figures on the computer screen according to transformations or mapping rules (i.e., maps) specified by the user. The program enables students to design and experiment visually with maps specified by mathematical functions, algebra formulas, and geometric transformations and to investigate their properties and uses experimentally through an extensive set of constructionist activities.

A Brief Overview of MultiMap

MultiMap has a direct manipulation iconic interface with extensive facilities for creating maps and studying their properties under iteration. The user creates figures (such as points, lines, rectangles, circles, and polygons), and the program graphically displays the image of these figures as transformed by the map, possibly under iteration. MultiMap allows one to make more complex maps out of previously created maps in three distinct ways: by composition, by superposition, or by random selection of submaps. It includes a facility for coloring maps by iteration number, a crosshair tool for tracing a figure in the domain to see the corresponding points in the range, and a zoom tool for magnifying or contracting the scale of the windows, MultiMap also enables the generation and investigation of nonlinear maps that may have chaotic dynamics.

The program supports the creation of visual figures that are often ornate and beautiful such as self-similar mathematical objects of many kinds called fractals. The term “fractal” designates the convoluted curves and surfaces that exhibit self-similarity at arbitrary scales (Mandelbrot, 1983). Using MultiMap, with minimal guidance from an instructor, students have discovered such phenomena as limit cycles, quasi-periodicity, eigenvectors, bifurcation, fractals, and strange attractors (Horwitz and Eisenberg, 1992).

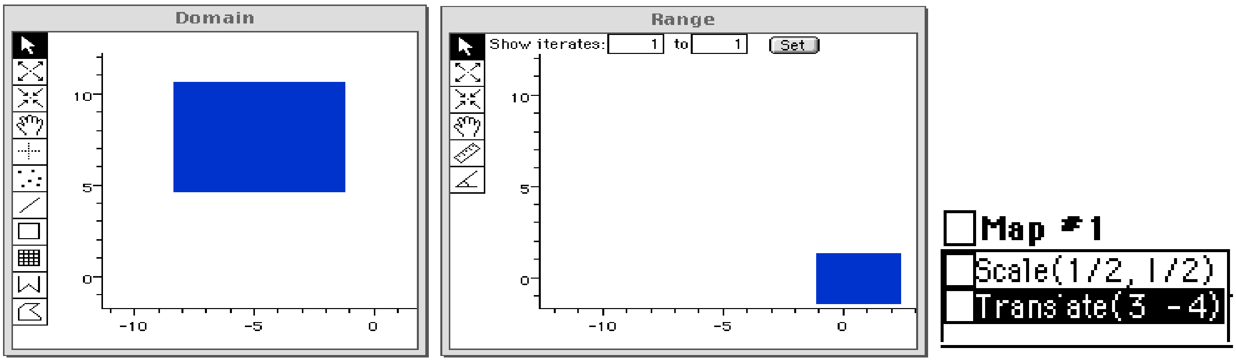
The MultiMap screen is divided into three windows as shown in the following figure. The user draws shapes such as points, lines, and polygons in the Domain window, using the iconic tools shown in the palette on the left. The computer draws the corresponding images of whatever shapes are drawn in the domain. The Map window specifies the transformation of points in the domain that “maps” them into the range. The user controls what the computer draws in the Range window by specifying a mapping rule, expressed in the form of a geometric transformation. The image specified by the map, drawn on the Range window, is computed for the entire plane. In the figure, the user has entered a rectangle in the Domain window and has then specified a map composed of two submaps, a scale and a rotation. Scale (0.8, 0.8) scales the rectangle to 0.8 of its original size in both x and y. Rotate (90 °) rotates the rectangle 90 degrees about the origin. In a composition map such as this, the transformations are performed in order. Thus the rectangle is scaled and then rotated. This is an iterated map. The user has specified that the map is to be performed 4 times with a distinct color for successive iterations (light blue, green, red, and pink.) The Range window shows the result of the mapping.



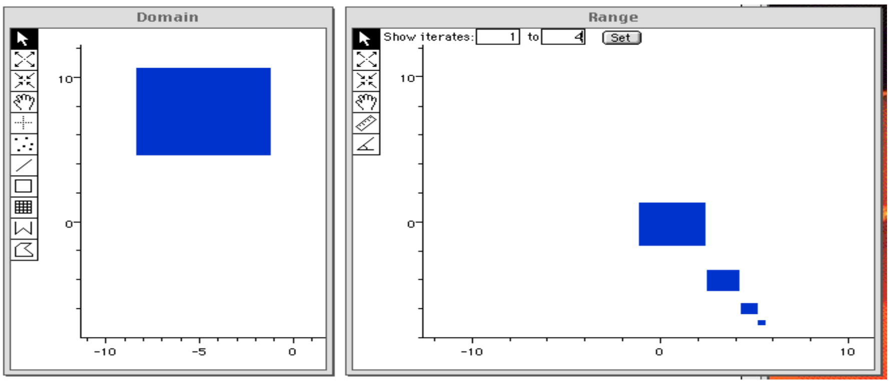
Iterated Scale and Rotation Map

Using MultiMap, students from local high schools created and investigated simple maps built on the familiar operations of rotation, scaling, and translation. Students were introduced to rotation, scale, and translation maps during their first sessions, and to their properties under composition and iteration. They then investigated the behavior under iteration of more-complex maps, including maps that produce beautiful fractals with self-similar features at all levels, random maps that generate regular orderly structures, and maps that, though deterministic, give rise to unpredictable and highly irregular behaviors.

The program has a direct manipulation iconic interface with extensive facilities for creating maps and studying their properties. The simplest geometric maps are created from primitive operations such as rotation, scaling, and translation. The user creates figures (such as points, lines, rectangle, and polygons) and the program graphically displays the image of these figures transformed by the map. The user also can specify a mapping function algebraically. For example, the function X' -> X/2 , Y' -> Y/2 will reduce figures to half their original size, and the function X' -> X + 3 , Y' -> Y - 4 will translate figures three units forward and four units down. MultiMap allows one to make more complex maps out of previously created maps. For example, the two functions described above can be composed (i.e., performed jointly) with the result shown below. As the figure shows, the rectangle that is input to the Domain window is scaled to half size and translated forward three units and down four units. The inset from the MultiMap control window shows the specified mapping operations.



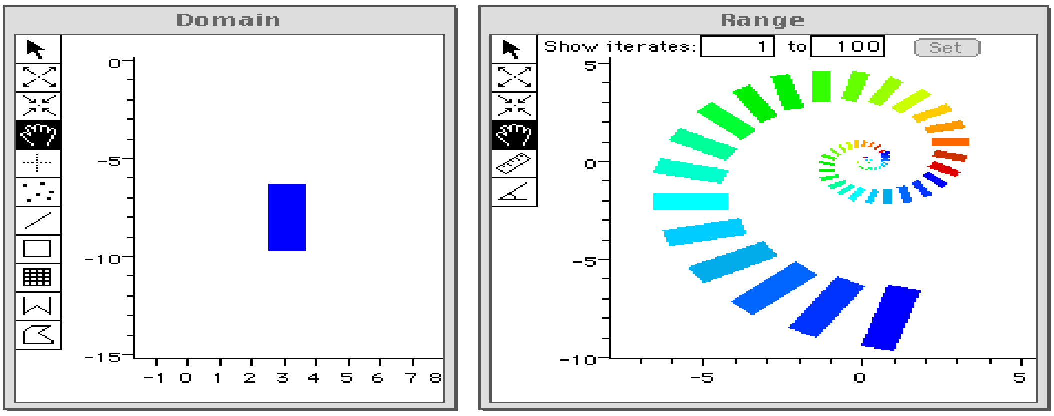
A user can repeat a mapping process an arbitrary number of times to generate a sequence of images. For example, when the mapping functions above are repeated four times in succession, the result is shown in the following figure.



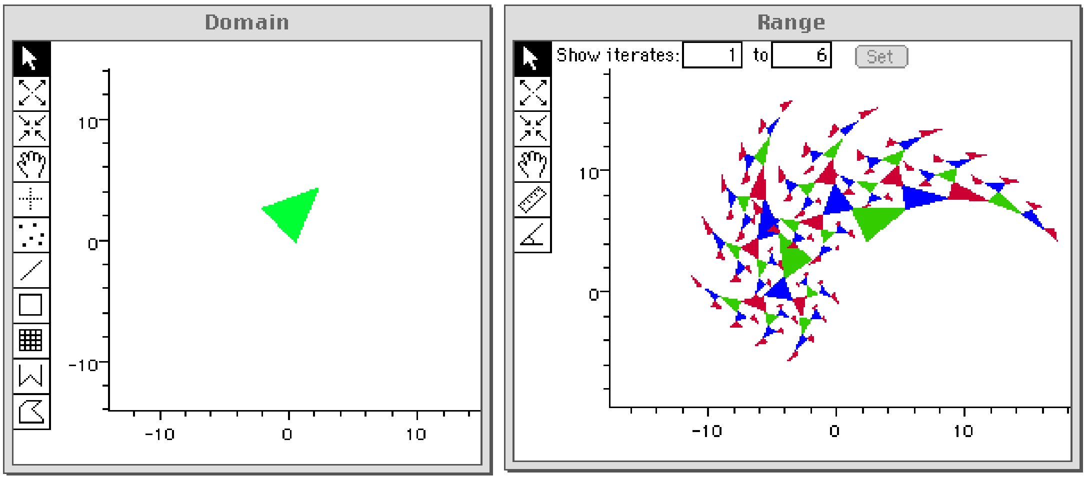
Iterated Scale and Translate Map

As the figure illustrates, MultiMap can display the limiting behavior of functions when they are iterated many times. Only one of three things can happen: successive iterates of the function may approach a single fixed point; they may converge to a limiting orbit of points; or they may behave more erratically, never quite returning to a value they have taken on before. Through investigating these situations, MultiMap can be used to provide students a clear and accessible introduction to sequences and limits, and a natural environment for investigating their behavior.

For example, students can create and investigate geometric sequences such as the following. (Color is used in these to show clearly the pattern of successive iterates, rather than for decorative effect, though it does heighten the aesthetic aspect of the mathematical structures.)



A Rectangular Spiral



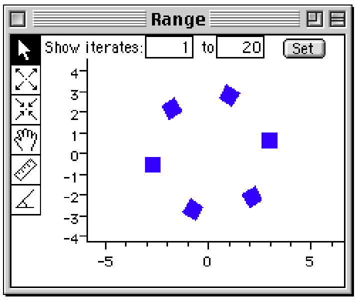
A Triangular Branching Pattern

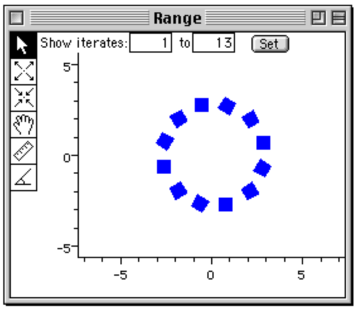
MultiMap connects the algebraic and geometric representations so that they are mutually supportive. The algebra helps students' understanding of the geometry, and vice versa. The software provides a variety of tools to aid exploration and investigation: a facility for coloring maps by iteration number (as illustrated above), a crosshair tool for tracing an input figure in the Domain window to generate the corresponding image in the Range window, a zoom tool for magnifying or contracting the scale of the windows, and a number of other tools to aid mathematical investigations. The program facilitates the creation of self-similar figures, and allows one to produce figures that are often very ornate and beautiful.

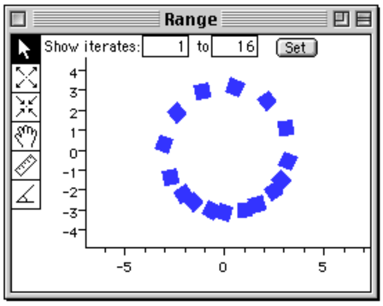
MultiMap enables students to engage in a rich variety of mathematical investigations. Its visual representations significantly aid in understanding function, iteration, algorithm, transformation, model and other key mathematical concepts. We have piloted the use of MultiMap with secondary students and teachers in algebra, geometry, and computer science classrooms and teacher institutes. The program has been used by over 50 math teachers who have demonstrated students' learning benefits and mathematical empowerment from working with MultiMap. Teachers find it easy to use and learn to write relatively complex programs. Through their work with MultiMap, students find that doing and learning mathematics can be *fun*.

A Student Session

The following session illustrates the use of MultiMap by two students, Kate and Fred, working together on an investigation of rotational symmetry (Horwitz and Feurzeig, 1994). They began by drawing a square and rotating it by 60 degrees, as shown on the left figure below. They noted that the 6 copies of the square lay around a circle centered at the origin, and that, though the map was iterated 20 times, after the first 6 iterations the others wrote over the ones already there. They were then asked what the result of a rotation by 30 degrees would be. Kate said that there would be 12 copies of the square instead of 6, no matter how many iterations. They confirmed this, as shown in the middle figure. The instructor then asked “What would happen if the rotation angle had been 31 degrees instead of 30?” Fred said “There will be more squares—each one will be one more degree away from the 30 degree place each time, so the squares will cover more of the circle.” MultiMap confirmed this, as shown in the figure on the right



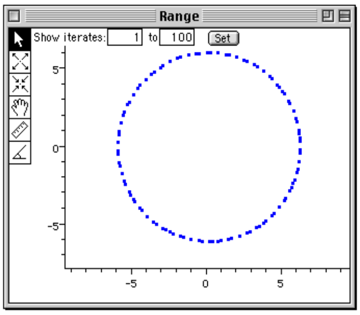


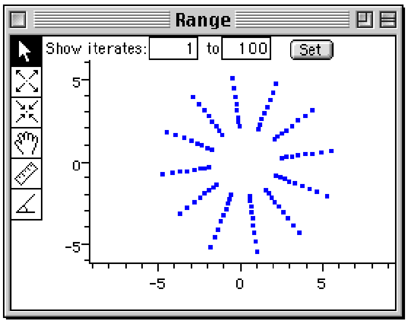


R(60) *R(30)* *R(31)*

Instructor: "*The picture would be less crowded if the square was replaced by a point.*" Fred made this change. The result, after 100 iterations, is shown below on the left.

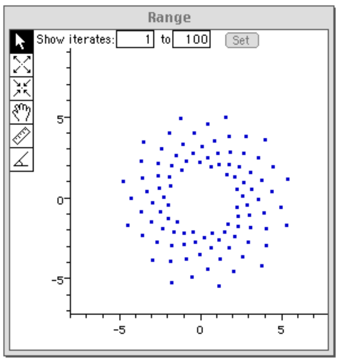
Since there was still some overlap, the instructor said "After each rotation let's scale x and y by .99. That will bring the rotated points in toward the center a little more at each iteration." Ann then built an R(30°)S(0.99, 0.99) composite map. The effect of the scaling is shown below on the right.

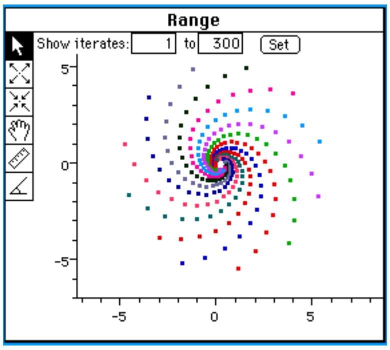




R(31) With Points *R(30)S(0.99, 0.99)*

Fred: "*Now the points come in like the spokes of a wheel with 12 straight arms*. The instructor then asked what would happen if the rotation were 31 degrees instead of 30.

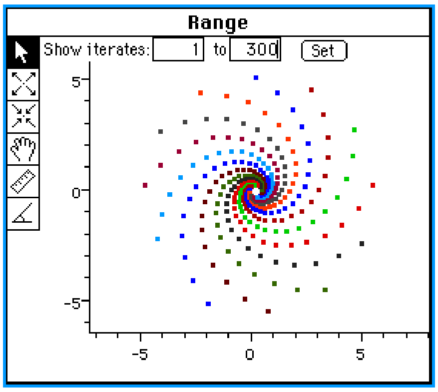


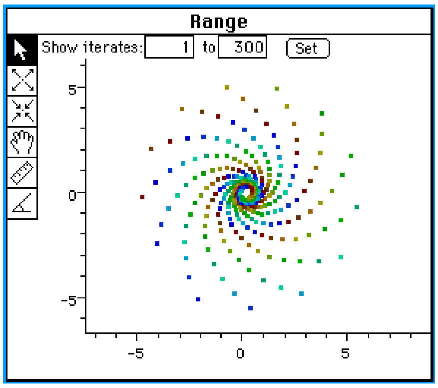


*R (31) * S (.99, .99)* *R (31) * S (.99, .99) 12-color ramp*

Fred replied "It would be almost the same but the points would not be on straight lines. He tried this. The result is shown on the left above. Kate said "The spokes have become spiral arms." When asked how many arms there were, she said "It looks like 12." The instructor said "Let's check that by making the points cycle through 12 colors repeatedly so that successive points have distinct colors.” The result is shown above on the right. Kate: “Oh, how beautiful! And now each arm of the web has the same color.” Fred: “Right, and we can clearly see that the web figure has 12-fold symmetry. Instructor: “What do you think will happen if the rotation is 29 degrees instead of 31 degrees?” Kate: “I think it will be another spiral, maybe it will curve the other way, counter-clockwise. But I think it will still have 12–fold symmetry. Here goes!”

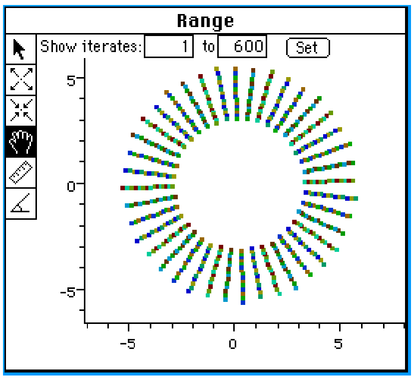
The result is shown below on the left. Instructor: “*Right! It goes counter-clockwise and it does have 12–fold symmetry. Very good! Now let's try a rotation of 27 degrees. What do you think will happen?”* Kate: “*I think it will be about the same, a 12–fold spiral web, maybe a little more curved.” The result is shown below on the right.*

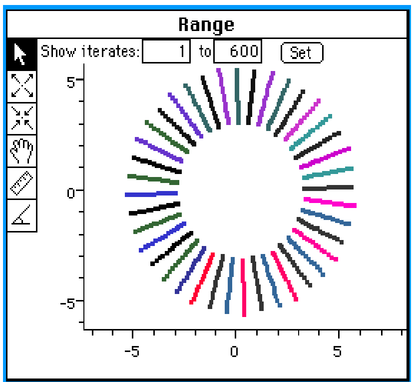




*R (29) * S (.99, .99) 12-color ramp* *R (27) * S (.99, .99) 12-color ramp*

Instructor: “*It might be that we don't have enough detail—let's get a more detailed picture by changing the scale from .99 to .999, and increasing the number of iterations from 300 to 600. See if that makes a difference*.” The result, after 600 iterations, is shown below on the left. Kate: “*Wow, it looks very different now! There are many more than 12 arms, but they're all straight,*





and each arm still has many different colors.” Instructor: “*There's obviously much more than 12–fold symmetry here. Any idea what it is*?” Fred: “*120*.” Instructor: “*Why do you say that*?” Fred: “*Because 360 and 27 have 9 as their greatest common divisor. So 360 divided by 9 is 40, and 27 divided by 9 is 3, and 40 times 3 is 120.*” Instructor: “*What do you think, Kate*?” Kate: “*I don't know but I counted the arms and it looks like there are 40*.” Instructor: “*Let's see if that's right. Reset the color map so that the colors recycle every 40 iterations instead of every 12 iterations*.” The students changed the color ramp. The result, after 600 iterations, is shown below on the right.

*R (27) * S (.999, .999) 12-color ramp* *R (27) * S (.999, .999) 40-color ramp*

Kate: “*Now each arm is the same color. So there is 40–fold symmetry*.” Fred: *Is 120 wrong?*

Instructor: "*No, 120 isn't wrong but it's not the only or the best answer. 240 and 360 would work and so would any other multiple of 120. But the real question is: what is the smallest one? The way to view the problem is this: what is the least number of times you have to go around a circle in 27-degree increments to come back to where you started? Or, to put it another way, what is the smallest integer N such that the 27 times N is an exact multiple of 360? The answer is 40 because 40 times 27 equals 1080, which is 3 times 360. No integer less than 40 will work." Fred: "I understand. Now I can do the problem for any angle*."

Investigating the Mathematics of Fractals and Chaos

We have begun to investigate the use of MultiMap on a rich variety of topics including the mathematics of chaos, fractals, and nonlinear systems. We seek to develop a coherent conceptual framework for introducing the key ideas at a level appropriate for high school presentation. To this end we are creating software tools designed to aid students in carrying out mathematical experiments and explorations. These tools will enable students to build and run models of dynamic systems with complex behaviors, to see their effects unfold, and to manipulate and study the generated graphic structures in multiple representations and at multiple levels of detail. We have started to design learning activities centered on the use of the tools and to develop organically the knowledge needed to use them effectively.

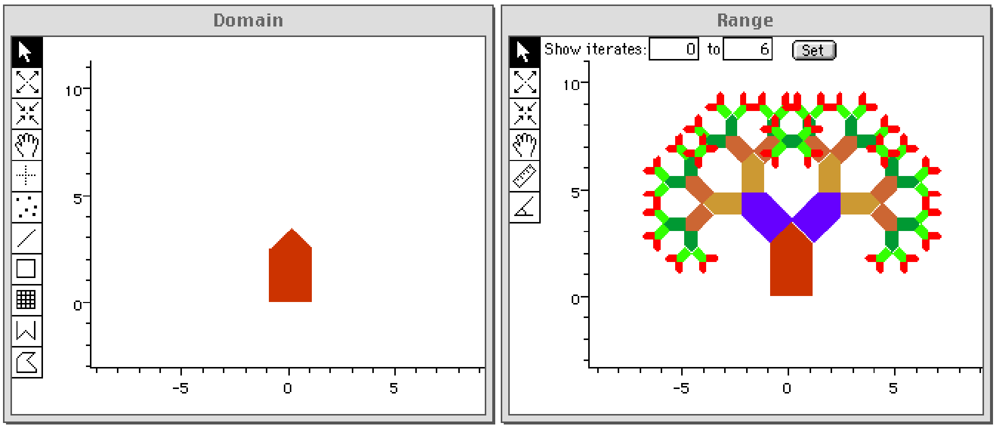
We believe that a nontrivial introduction to the ideas and methods of chaos can be developed and presented in a way that is both accessible and compelling to a significant fraction of pre-college students. This material is ideally suited to give students authentic experience of what doing mathematics and science is really like in areas that are meaningful and truly interesting to them. It provides rich opportunities for successful mathematical exploration, inquiry, and discovery. We plan to generate projects in relatively uncharted areas where it is possible for students to make new findings. In introducing students to the concepts and techniques of mathematical chaos we are placing them in a position to conduct investigations in a manner quite analogous to that employed by professional mathematicians.

Despite its modernity and complexity, an introductory presentation requires little mathematics beyond high school algebra. Moreover, the animated visual displays of chaotic processes greatly facilitate understanding of the deep connection between chaos and fractal geometry. The graphic pictures that are generated as natural outputs of investigations are often breathtakingly beautiful objects in their own right — the connection between mathematics and visual art has never been so apparent.

We introduce the subject of mathematical chaos to students by first familiarizing them with three fundamental concepts: iterated functions, maps, and fractals. Students then explore a wide variety of applications of chaos, e.g., to classical mathematical problems such as finding the roots of an equation; to the modeling of non-linear systems, such as the growth and decline of animal populations, the spread of infectious disease, the beating of the human heart, and the creation of fractal art and music. The use of MultiMap enables students to gain insights from visually rich mathematical explorations such as investigations of the self-similar cyclic behavior of the limiting orbits of rotations with non-uniform scaling (Horwitz and Feurzeig, 1994) and a better understanding of the deep issues underlying the solution of polynomial equations by generating maps that relate alternate representations of mathematical universes such as quadratic polynomials (Feurzeig, Katz, Lewis, and Steinbok, 2000).

The phenomenon of chaos is intimately linked to the behavior of functions, often very simple ones, when iterated many times. Only one of three things can happen: successive iterates of the function may approach a single fixed point; they may converge to a limiting orbit of points; or they may behave more erratically, never quite returning to a value they have taken on before. In the last case the iterated function sometimes displays an extremely sensitive dependence on initial conditions, so that neighboring starting points, when operated on repeatedly by the function, diverge very rapidly from one another, and all information about the starting point is lost. Behavior characterized by such an extreme sensitivity to initial conditions has been termed chaotic. The successive values taken on by the function closely resemble a random sequence, and indeed chaotic functions can be used as pseudorandom number generators. Because of their sensitive dependence on initial state, mappings of chaotic functions often display nearly self-similar structure on an infinitesimal scale, giving rise to curves and surfaces of fractional dimension, or fractals.

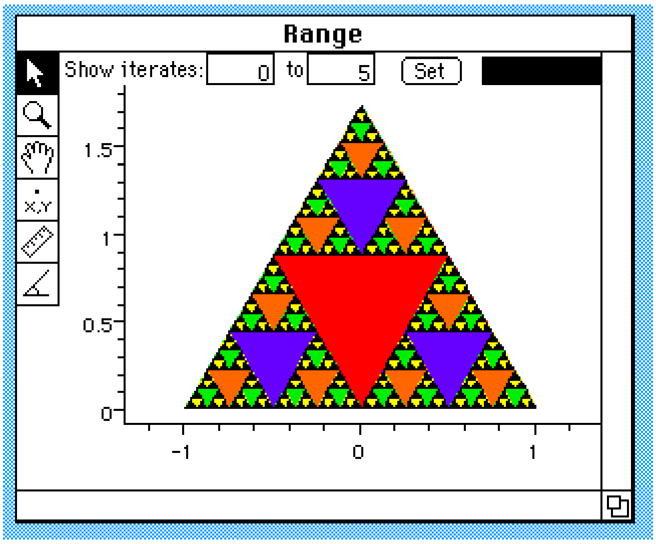
Fractals depict the convoluted curves and surfaces that exhibit approximate self-similarity at arbitrary scales (Barnsley, 1983). They can represent realistic images of natural objects such as flowers, clouds, and mountains. They can be amazingly complex and are often very beautiful. Fractal structures can be thought of as having non-integral dimensions. By virtue of its ability to generate recursive maps, MultiMap becomes a kind of “Fractal Construction Set” that enables students to create, modify and investigate fractals as objects of interest in their own right, even before they discover the deep connection of fractals with the phenomenon of chaos. For example, objects such as the fractal tree shown in the next figure, the result after several iterations of building scaled (doubled) rotated copies at each iteration, starting from the basic generating figure shown in the Domain window.



Generating a Fractal Tree

MultiMap supports recursive maps. It can map window A onto window B and then map window B back onto window A. This makes it a valuable tool for the study of iterated functions. For example, students can use MultiMap to construct pictures that contain "infinitely many" reduced copies of themselves. Such pictures can be constructed simply by creating a reduced scale mapping from one window to another, and then mapping the second window back onto the first, appropriately positioned. The iteration of these “condensation maps” often results in the creation of pictures that mimic such naturally occurring objects as ferns and clouds (Barnsey, 1986). In addition to being inherently interesting to students, these pictures illustrate the important idea of invariance under a scale transformation — an idea that underlies the concept of a fractal.

The following two figures illustrate the application of iterated maps for generation of fractal structures in MultiMap. The first one shows the "Sierpinski gasket", the result after three iterations of building successively compressed and three-fold multiplied copies of an embedded triangular pattern.



Sierpinski gasket

The generating figure, the initial iterate, is the large red triangle. The first iterate comprises the three blue triangles; the next two iterates are the nine orange triangles and the twenty-seven green triangles.

From High School Algebra to Chaos

Iterated maps are also useful in traditional mathematical activities, such as finding the roots of equations. One such application is to Newton's method, a well-known iterative procedure for locating the roots of equations in the complex plane. It can serve as an alternative to the quadratic equation formula routinely taught in high school algebra. It has the additional advantage that it can be generalized to finding the roots of cubic and higher-order polynomial equations, and that it can be motivated and justified to students via an appropriate graphical representation.

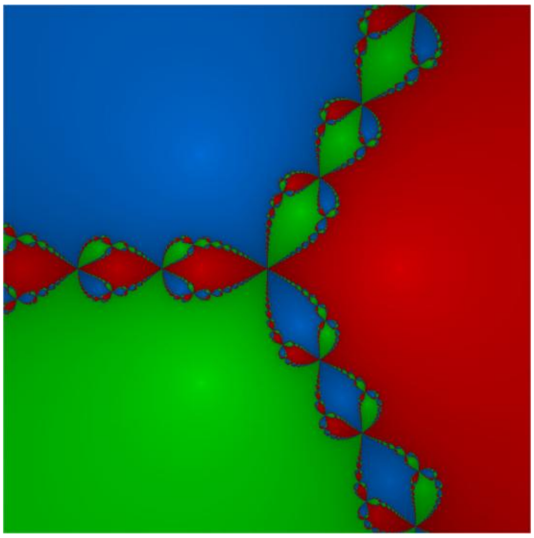
We introduced Newton's method in the context of quadratic equations, with which students were already familiar. We presented it initially merely as an alternative to the usual, somewhat mysterious formula. The method starts with an initial guess and then employs the repeated application of an algorithm that ultimately converges on one or the other of the two roots. We then posed the question: how does the choice of the initial guess determine the future behavior of the process? In particular, which of the two roots does the process ultimately converge on, and which initial guesses, if any, will result in its never finding a root? To answer this question, students began by using MultiMap to determine by trial and error the regions in the complex plane for which starting guesses converge to one or another of the roots of the equation.

For quadratic equations the solution is not surprising: connect the two roots by a straight-line segment and construct the perpendicular bisector of this segment. Then the "basin of attraction" of each root (that is, the set of all initial points for which the method converges to that root) is simply the open half plane on one or the other side of the perpendicular bisector. Points on the bisector itself do not converge to either root and in fact their behavior is chaotic, in the sense that the behavior under iteration of neighboring points diverges very rapidly, so that all information relating to the initial point is lost. In modern terminology, the perpendicular bisector comprises the so-called Julia set of the iterated rational function that characterizes Newton's method.

This new kind of exploration, in which one asks about the behavior of an iterated function at each point in the complex plane, requires a new kind of software tool — one capable of producing a variety of new kinds of mappings. The most obvious mapping simply assigns a different color to each pixel on the screen depending on the behavior of the iterated function at the corresponding point on the complex plane. Thus, a natural map of the situation described above is to color all points in the basin of attraction of one of the roots of the quadratic equation red, say, and of the other, green. This procedure divides the plane into two equal colored regions, separated by a straight line.

We then show students how to generalize Newton's method from quadratic to cubic equations, and give them the task of mapping out the basins of attraction of each of the three (complex) roots. Students expect the plane to be divided into three distinct regions, corresponding to the basins of attractions of the three cubic roots, just as the plane separated the basins of the two roots into two distinct regions for the quadratic equation.

However, the resulting map behaves very differently. It generates an extremely complicated and quite unexpected fractal picture as shown in the following figure. The reason for such remarkable behavior is simple. It can be rigorously shown that in the neighborhood of the Julia set (that set for which the function "cannot make up its mind" which of the three roots to converge to) there must be points belonging to each of the three basins of attraction at any level of iteration. In geometric terms: coloring the roots (say, red, green, and blue) at any point where any two regions (say red and green) come together, the other (blue) region must meet both of them, as well! There is no root-free boundary separating the regions. The structure is a fractal whose inner structure is repeated at finer and finer scales. MultiMap can demonstrate this strange phenomenon. Before representing the map, however, and after some consideration of this startling explanation of its behavior, the user may well have come to the conclusion that this situation is impossible. It is *not*, as the following figure depicting its behavior shows.



Cubic Roots Fractal

The observation of such astounding behavior motivates an introduction to the study and investigation of mathematical chaos. MultiMap provides users a powerful tool for experimental investigation of chaotic maps, those where the sequence of points generated by iterating the map exhibit “exquisite sensitivity” to initial conditions. (Horwitz and Eisenberg, 1992) describe and illustrate several such activities.

The properties of simple functions iterated many times are wonderful, unexpected and beautiful, but they may be expected to fall outside the set of inherently interesting topics for most high school students. To someone for whom the solving of equations — even beautiful ones — is not particularly motivating, the fact that this task can be accomplished through iterating a simple function is unlikely to be of lasting interest. It is important, therefore, to move on to activities in which the iteration of a function implies something more than merely finding the roots of an equation.

An obvious choice, and one that has rich mathematical and scientific applications, is to model a variety of processes that evolve in time. Each successive iterate of the function may be taken to represent a fixed time interval. If this interval is long enough to produce significant changes in the variables the resulting equation is a finite difference equation; if it is short on this scale, it approximated as a differential equation. Without the computer and an accessible tool like MultiMap, it would be unrealistic to attempt to introduce differential equations to the high school mathematics curriculum. However, once one has made a connection in students' minds between iterating a function and modeling a time-evolving process, the transition becomes natural and compelling, especially when introduced in the context of real-world situations such as prey-predator interactions, the spread of contagious diseases, and environmental recycling strategies. Many other areas of application are rich candidates for student projects with MultiMap.

The development of MultiMap in the NSF project “Advanced Mathematics from an Elementary Viewpoint” has been described by Feurzeig, Horwitz, and Boulanger (1989). Early versions were implemented on Macintosh desktop and laptop systems. We are currently implementing a new version for tablet systems such as the Apple IPad together with an additional body of project-based activities and supporting curricular materials.

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Representational congruence: Connecting video game experiences to the design and use of formal representations

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Abstract

Video games designed for educational purposes often struggle to effectively connect concepts of interest to gameplay. We propose that to encourage players to mobilize knowledge resources for non-game settings such games must be representationally congruent. Representationally congruent games are construction games where the player builds and/or interacts with the game using primitives relevant to the game world to construct representations that are congruent with those used by domain experts in the real world. Showing data of players constructing velocity v. time graphs before and after playing a representationally congruent racing game, we argue that the shared features of player-constructed and formally accepted representations provide a hook for players to bring knowledge and intuition built in-game to situations and experiences outside of the game context.

Keywords

Video games, representations, physics, graphing, knowledge resources

Introduction

Video games have recently been a popular object of study in the educational community. New research claims video games can serve as powerful spaces to teach critical thinking, spaces for trying on new and refining one's own identity, and can serve as a binding agent for real-world interaction (Gee, 2003; Ito, 2009; Squire, 2006). Furthermore, games are highly motivating and have become a central feature of current youth culture. Recent studies suggest that as many as 97% of all American teens (regardless of gender, age, or socioeconomic status) play video games in some way and 50% play games daily for an hour or more (Lenhart et al., 2008). As an activity so central to children's lives, video games are a space ripe with potential. Our research agenda is to strive to make game play, a space that likely contributes much to children's intuitive notions of physical phenomena, a rich experience for deep exploration and meaningful knowledge construction.

Providing a space for knowledge construction doesn't mean we must transform games into something resembling a traditional classroom, nor does it mean games should be played in the classroom. As Papert (1996) noted, "The best learning is learning that is embraced and enjoyed. Children love to learn until they are taught otherwise" (p. 51). While I believe popular, and fun, commercial games do provide opportunities for players to explore and experiment with important mathematical and scientific ideas, these ideas are often backgrounded in favor of gameplay and obscured by visual effects essentially tying the constructed knowledge structures to the game space. The notion of a "play paradox," proposed by Noss & Hoyles (1996) highlights the difficulty in designing playful experiences that provide powerful opportunities for learning. If specific interactions are prescribed to ensure the experience the designer is interested in occurs, it is no longer play. However, if play is held sacred, valuable learning experiences might be passed by.

We, and a handful of our colleagues, believe that carefully designed constructionist video games may provide a solution to the play paradox. Because video games are necessarily constrained to have "quantifiable outcomes" (Juul, 2005; Salen & Zimmerman, 2004) – to have a win condition – certain interactions or pathways through the game are guaranteed. Of course this idea of constraining the possible space of exploration does interfere with how a child interacts with the game somewhat. However, deliberately including opportunities for personal construction within this space harnesses the power of constructionist design, encouraging players to build new ideas and strategies using the rules of the game world even as they pass prescribed goals (for more on the designing constructionist video games see (Holbert, Penney, & Wilensky, 2010; Weintrop, Holbert, Wilensky, & Horn, 2012).

For a game to be truly constructionist we believe the concepts to be explored and the gameplay must be what Kafai (1996; 1998) and Habgood and Ainsworth (2011) call *intrinsically integrated* and Clark and Martinez-Garza (in press) refer to as *conceptually integrated*. Conceptually integrated games directly tie the gameplay to the concepts of interest. So rather than interrupting the "fun" part of the game for mandatory multiple choice questions (a common game design of the *edutainment* industry), conceptually integrated games make the content of interest the mode of interaction. In short, in conceptually integrated games, play is learning.

In this paper we propose a new design principle central to developing constructionist video games. We argue that in addition to being conceptually integrated, video games designed to provide a space for personal construction must also be representationally congruent. Representationally congruent games are construction games where the player builds and/or interacts with the game using primitives relevant to the game world to construct representations that are congruent with those used by domain experts in the real world. In such games the primitives for construction embody the content (as in conceptually integrated games), but by putting them together in personally meaningful ways, the resulting representation has meaning outside of the game.

To further explain the design behind and value of representationally congruent games, we provide examples from our own game *FormulaT Racing* (FTR), a racing game for exploring kinematics. In this paper we will describe important representations included in the construction tools of FTR. We will then present an analysis of a pre- and post-game graphing task completed by FTR players to argue that this important design feature allows players to mobilize knowledge resources gained from playing the game when reasoning about related non-game problems.

Theoretical Framework

The notions of conceptually integrated and representational congruent design can trace their roots back to Papert's (1980) most famous transitional object, the LOGO Turtle. The power of the Turtle is that it embodies not only the users sense of motion and mathematics in the real world, but also the rules and features of formal mathematics – essentially "standing between the concrete/manipulable and the formal/abstract" (Noss & Hoyles, 1996).

The Turtle is often described as "body-syntonic." Papert (1980) suggest "children can *identify* with the Turtle and are thus able to bring their knowledge about their bodies and how they move into the work of learning formal geometry" (p. 56). For example, by "playing turtle" the child can actually feel the appropriate moves necessary to walk out a square. In this way the idea of "squareness" isn't relegated to some abstract formula or set of rules and heuristics. It is instead a very real, and incredibly obvious thing – so obvious in fact that children sometimes have a difficult time using words to explain it! And because the words of the Turtle match the language of the child, creating a square, a triangle, or even a circle, is as simple as telling a friend how to move around in a room.

While playing turtle feels natural, and the language used to command the Turtle match the language a child uses to describe her own motion in the world, the ideas enacted by the Turtle, and representations created by the Turtle, are very much mathematical. Whether constructing a house, a spiral, or a complex animation, the structures created by LOGO users embed highly formal rules and look remarkably like constructions one might find in the formal practices of engineers or computer animators. In this way creating with the Turtle not only allows the user to draw on her own sense of navigation in the world, but also to create artifacts that have value beyond the computer screen they're constructed on.

Conceptual Integration

The term *conceptual integration*, or *intrinsic integration*, was used first by Kafai (1996) to describe a specific categorization of games created by children as part of the instructional design project. Kafai describes these games as those where the "designer integrates the subject matter with the game idea" (p. 82). Kafai likens these games to microworlds (Papert, 1980) but claims that very few students created games that fit this category.

Recently, as video games become an even more popular space for educational design, the idea of intrinsic, or *conceptual*, integration has been utilized by Habgood and Ainsworth's (2011), Clark and Martinez-Garza (in press), as well as our own work in game design. In Habgood and Ainsworth's (2011) *Zombie Division*, the various modes of attack embody the fractions of interest. For example, players using a sword effectively "divide" the zombie in two while punching using a five-fingered glove divides the zombie by five. Clark and colleagues (2011) provide another example of conceptual integration in their game *SURGE*. Here players use impulses and moments of constant, positive, and negative acceleration to navigate a spaceship through a maze. In our own *FormulaT Racing* (Holbert & Wilensky, 2010a), which we will discuss in more detail in this paper, players use motion-sensitive controls to apply positive and negative acceleration to a racecar to complete various challenges.

Unfortunately, conceptually integrated games often fall victim to the play paradox. Clark and Martinez-Garza (in press) argue, "Though playing a conceptually-integrated game engages the player constantly in the targeted relationships, the player may never articulate or even identify those relationships." In an effort to overcome this problem, we propose the principle of representationally congruent design.

Representational Congruence

As mentioned previously, representationally congruent games are construction games where the conceptually integrated building primitives that make sense in the game world are used to construct representations congruent to those used in the real world. In these games the representations created by players should resemble those used in the real world by those that do serious work with the game-embedded content. This isn't to say that the goal of a representationally congruent game is to *teach* players to make these formal constructions. Far from it! Rather, we believe that when constructions created by players in the game share some resemblance to formal representations used outside of the game, players will see the processes used to make these construction as equally relevant in non-game spaces.

Interestingly, while conceptually integrated video games often are not representationally congruent, edutainment games — education games where the content of interest is *not* conceptually integrated to the game action — often go to great lengths to include relevant formal representations of the content. However, because these games lack meaningful construction primitives — primitives that have conceptual meaning — we would argue that these games are *not* representationally congruent. For a game to be representationally congruent, we believe it must involve meaningful construction with primitives that are themselves conceptually integrated, to create representations relevant to expert use of the domain.

While video games designed to be representationally congruent are rare, constructionist software often embrace this design principle. Bamberger's (1996) Impromptu music software is an excellent example of software that includes important new representations to help users come to a better understanding of ideas like rhythm, but final constructions lead to representations and compositions recognizable by any musician. The programming environment Alice (Cooper, Dann, & Pausch, 2000), works especially hard to provide a space where users can experiment with object-oriented programming, quickly creating professional looking animations. However, while Alice is tile-based, "instructions correspond to standard statements in a production oriented programming language, such as Java, C++, and C#".

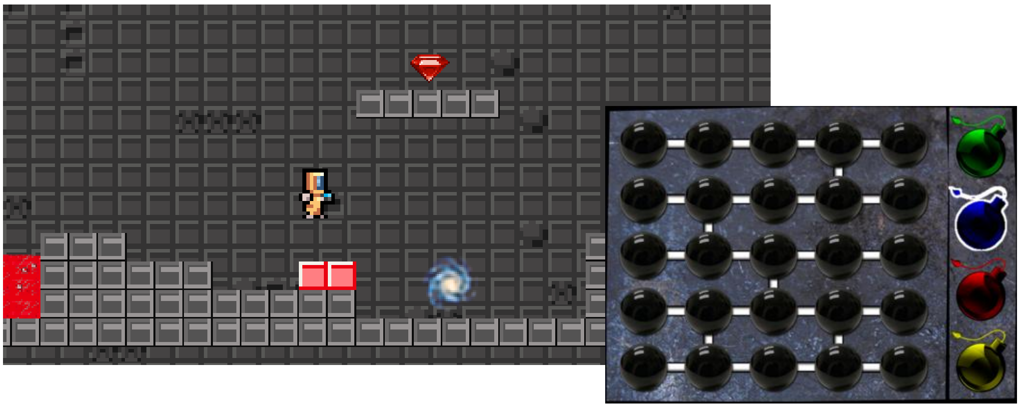

Figure 1. In Particles!, players rearrange bonds between atoms to create blocks in the game world that have physical properties emergent from the molecules constructed. Here the player has created a block with spring by cross-linking chains of atoms.

In our own game design work, representational congruence has been central. In *Particles!*, a platforming game we currently have under development, players organize the "atoms" of all structures and objects in the world (Holbert & Wilensky, 2012). By rearranging the atoms and bonds of a substance in the world the player alters its emergent physical properties (for example creating long cross-linked chains to create "bouncy blocks"), allowing them to develop novel solutions to each level. Here the actual objects that are arranged by the player do not accurately resemble real atoms, but final constructions made share features of traditional molecular models (Figure 1). In *FormulaT Racing* players use motion sensitive controls to accelerate points up and down a y-axis to ultimately construct velocity versus time graphs that the player car will then utilize when driving around the track.

Methods

In the remainder of the paper we present a study of *FormulaT Racing* intended to explore the value of designing games to be representationally congruent. Eleven players aged 8-14 were recruited from various informal organizations in a large midwestern US city. These players were told they would be helping us to evaluate a new game we were developing. Interviews with players were conducted before playing the game, then a week later participants played the game over two 1-2 hour play sessions before being interviewed again two days later. Of the eleven children that completed the pre-game interview, six completed the pre-game and post-game interview playing the same version of the game.

There are three main phases of FTR: skill development, racing, and constructing (a more detailed description of the design of FTR can be found elsewhere (Holbert & Wilensky, 2010b, 2011a). Of particular importance to this paper is the construction phase of the game, often referred to as the “pitboss” level. In this level, players are confronted with a birds-eye view of the entire track (Figure 2). Then, by clicking the track using the mouse (or touching the track on compatible devices), the player can paint it with different colors that each correspond to different vehicle velocities. Once the player has finished painting the track, the car in set in motion to drive around the entire track, increasing and decreasing its velocity as it moves over the player-added colors.

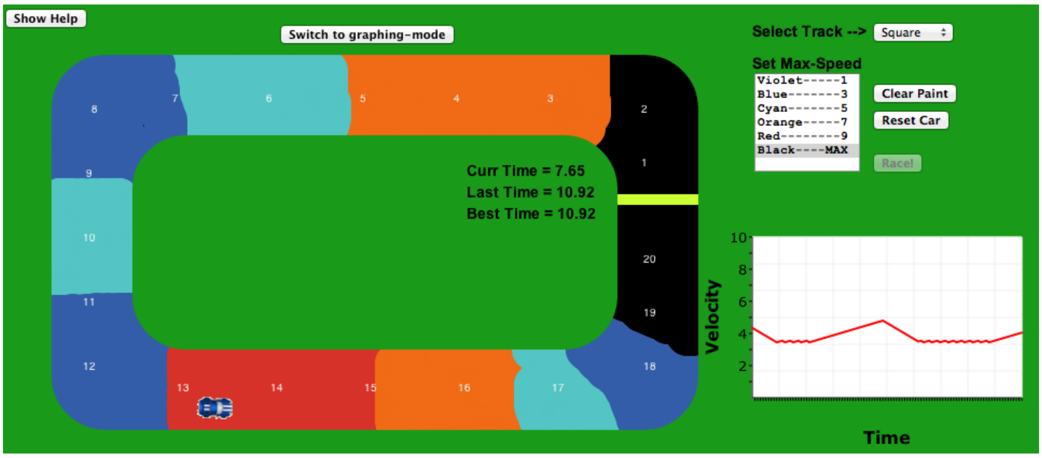

Figure 2. Players paint the track using colors corresponding to different velocities. When the car drives over the painted colors, it accelerates and decelerates until it’s velocity matches that of the painted color.

After successfully completing the three included tracks by painting, the player then begins the second stage of the pitboss level. In this stage the player must construct a velocity versus time graph that the car will then use to drive around the track. Using numbered markers distributed throughout the track, the player adds nodes to a graph to indicate the speed the vehicle should be traveling at that point (Figure 3). However, rather than simply “clicking” to add a point at the chosen velocity, the player “accelerates” the point using a motion sensitive controller. The controller used is the same the player has become familiar with in the previous racing phases of the game (the racing phase plays like a traditional racing video game) to accelerate his car around the track. By rolling the controller forward or backward the player can add positive or negative acceleration to each point until he is happy with its location on the y-axis. Like the painting stage, here the player must accelerate points on a graph over the course of the entire race, rather than accelerating the car in-the-moment.

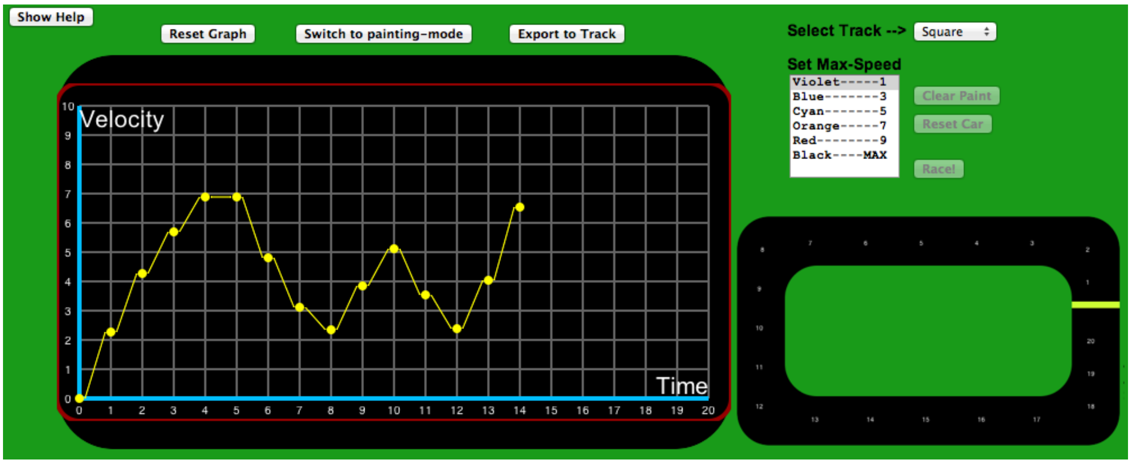

Figure 3. In the graph construction phase players accelerate points up and down the y-axis of a graph by rolling a motion sensitive controller forward (for positive acceleration) and backward (for negative acceleration).

In both the painting and graphing phases of the pitboss level, the player has the opportunity to make small or drastic changes to their constructions after the car has either crashed or made it around successfully. In previous work we have analyzed the systematic changes players made and found that players engage in sophisticated debugging of constructions and many even utilize complex repeating patterns, or "procedures," as they work to come up with a winning construction (Holbert & Wilensky, 2011b).

As previously mentioned, both before and after playing the game participants are interviewed by the first author and engage in a graphing task. In the graphing task participants are shown a paper speedometer (the term "speedometer" was never used by the interviewer though most participants identified it as such) with a movable needle. While the interviewer slowly manipulates the speedometer needle, participants are asked to "make a graph describing what I am doing with this meter." This is done on a piece of graphing paper with the x-axis pre-labeled "Time" and the y-axis pre-labeled "Velocity" (the interviewer takes time to ensure all participants are familiar with the term "velocity" ahead of time, and if they are not, informs them that it is "kind of like speed"). In the remainder of this paper we look at changes in pre- and post-game graphs created by players of FTR and argue these changes are due to interactions with the representationally congruent construction phase of FTR.

Results

Pre- and post-game graphs created by participants reveal that while many participants struggled in the pre-game graphing task (only two of eleven participants created qualitatively correct graphs in the pre-game interview), nearly all participants (five of six) were able to create qualitatively correct graphs during the post-game graphing task.

In the pre-game interview, most participants struggled to produce a graph of the changes being made to the speedometer. Once participants did begin constructing a graph, the graphs created were unlike those formally utilized by the physics and education communities. In one common pre-game graph, players utilized the pencil as if it were the actual car being described by the changing speedometer. In other words, while the researcher increased the speed on the speedometer, the participant would move his pencil across the paper faster, and when the speedometer was moved to a slower speed, the participant slowed his pencil down (Figure 4).

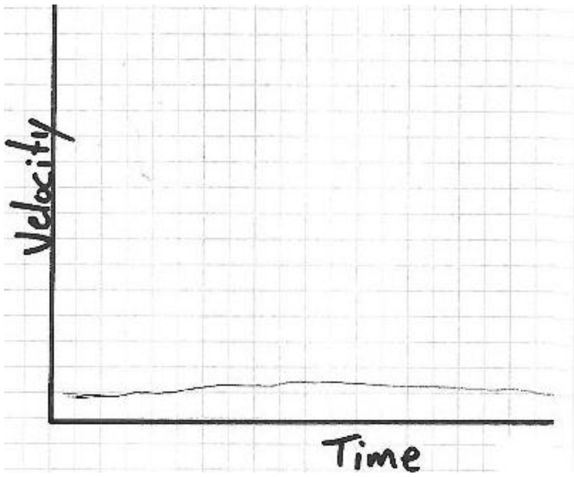

Figure 4. In the common pre-game pencil-as-car graph, the participant accelerates his pencil along with the changes to the speedometer as if the pencil is the car.

This common construction highlights the mismatch between intuitive ideas children have of motion and the formal representational system utilized by the expert community. Two explanations of what is happening seem possible. In the first, the pencil-as-car graph foregrounds acceleration, even though the representation itself only highlights this feature when it is constructed. Here, the participant knows that movement of the needle to a higher number on the speedometer means "going faster" and chooses to represent this *change* to a higher speed by gradually increasing his pencil movements. The other possible explanation is that the player is actually highlighting *velocity* rather than acceleration. In this explanation, while the player moves the pencil quicker when the interviewer changes the location of the needle, this movement only occurs due to his effort to show the pencil at a higher speed. Even though velocity could be made apparent by utilizing the y-axis of the graph, the participant's pencil movements are intended to show these discrete velocities, rather than the changes in velocity. Interestingly, both possible explanations point to a disconnect between acceleration and velocity. The participant is either showing *changes in velocity*, or *discrete velocities*, but makes no effort to coordinate the two. In this way the representation serves only to illustrate this one instances of motion, lacking the flexibility of formal velocity versus time graphs.

In the post-game interview, five of the six participants created qualitatively correct velocity versus time graphs. Two of the four participants that produced pencil-as-car graphs completed the post-game interview. Both of these participants created excellent velocity versus time graphs that contained important features such as differing amounts of acceleration and moments of constant velocity (Figure 5). A few features of these graphs stick out, notably, rather than simply draw a line to represent the motion, both participants added points at each time step. One participant that made a "correct" graph before playing the game, added points to his line in the post-game graphing task (points were not in his pre-game graph). While in any other circumstance this might not be very notable, the fact that in the graph construction level of FTR players accelerate "points" that are then connected by lines indicates the players are drawing directly on this in-game representation to accomplish this non-game task.

This point should not be understated. Players do not receive explicit instruction on creating graphs in the game and the tools (paper and pencil) and representations (speedometer) used in the interview protocol are completely absent from the game context. While it is true that player *do* create graphs in the game, this is done in a very non-standard way (accelerating points up and down the y-axis by tilting a motion-sensitive device) and no directions are given on exactly what a graph should look like. Instead, the game utilizes the interaction mechanism players have become used to throughout the game to drive the car. In this way the motion of tilting the controller becomes tied to the concept of enacting positive and negative acceleration, rather than game specific visualizations. This careful mapping of the interaction mechanism to the concept allows players to quickly map their ideas of a "successful run" to the kind of graph they want to create. The fact that participants were also are able to draw on this "graph construction" skill outside of the game context with different tools and representations is very exciting considering the large body of work that highlights the difficulty of learning to graph and even larger body of work that suggests transferring such skills or knowledge to a different context is an extremely unlikely occurrence.

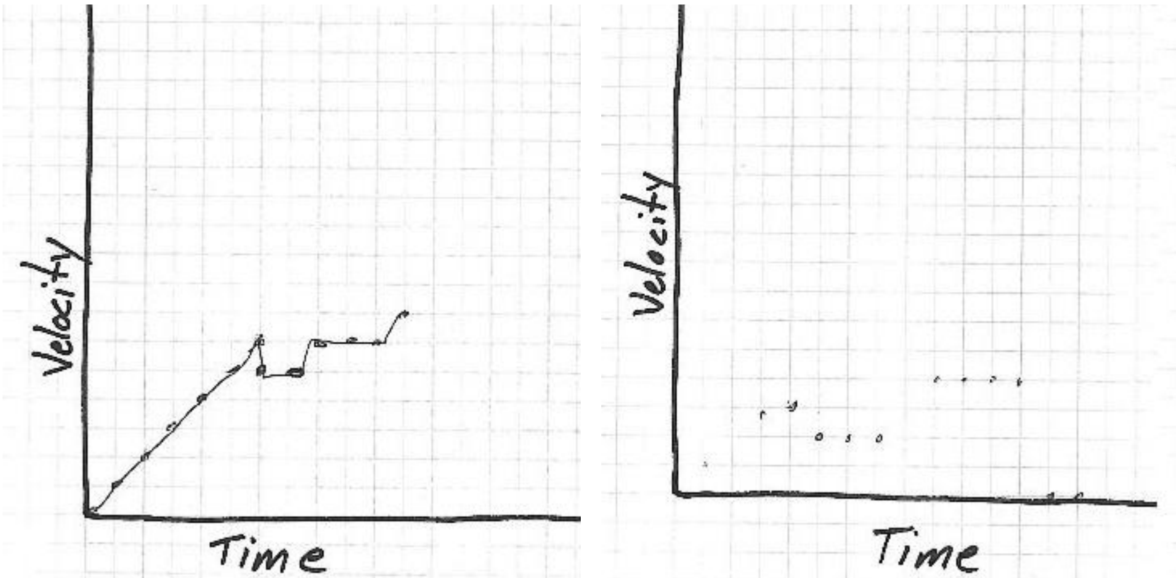

Figure 5. Two of the five qualitatively correct post-game graphs. These two graphs highlight the importance of "points" in the post-game graphs that was absent in all pre-game graphs.

Conclusions

Players of FormulaT Racing show a remarkable change in graphing ability between a pre-game and post-game graphing task. While players did see many, and even construct a few of their own, graphs in the game, the tools and representations used, as well as the context were completely different in the interview. We believe this data is evidence that as a representationally congruent constructionist game, FTR encourages players to see their experiences and constructions in-game as relevant in settings beyond the game.

But how does this happen? Since there is such a large body of literature that suggests "transfer" – using knowledge learned in one context in a new context – is so difficult, why were we so successful? A couple of different explanations seem possible.

One could argue that the context was not actually a new one – that the in-game graphing and post-game graphing task were not actually different contexts. This argument would likely be based on the one common feature between settings, the interviewer. One might claim that the participant has associated the interviewer with the game, and as such, the post-game interview was still an "in-game context." While this is a possible explanation, we believe the large collection of literature that presents "failures to transfer" where contexts were even more similar than the one is our study would suggest otherwise (Gick & Holyoak, 1980, 1983).

Another possible explanation, and the one we believe highlights the value of creating representationally congruent games, is that participants, recognizing the graph representation from their formal education, saw the activity they engaged in during the pitboss level of the game as relevant beyond the game. In this way, because the final representation of player constructions resembles representations used by experts in the domain, the *processes* and *primitives* used by the player to *construct* the representation are also seen by the player as relevant and "real." Essentially, the recognition of the representation outside of the game contexts activates knowledge resources the player has associated with the representation. These knowledge elements constructed while players used conceptually integrated building primitives in-game are highly useful not only for making the formal representation, but also for reasoning about relevant domain content.

If this is true, and we believe it is, then the shared features of player-constructed and formally accepted representations provide a hook for players to bring knowledge and intuition built in-game to situations and experiences outside of the game context. Those powerful moments of construction in FTR when players coordinate velocity (represented by the painted colors) to acceleration (though interactions with the motion sensitive controls) and tie these ideas to the relevant track features (such as straight-aways and turns) enriches previously held intuitive notions of motion.

These results increase our optimizm that informal video game play can be a powerful space for the exploration of science phenomenon. By carefully choosing interaction mechanisms and primitives for the construction component of video games, and by ensuring the final constructions will be seen as relevant to contexts beyond the video game, game-related knowledge resources created and refined by interactions with such games are then free to be utilized in non-game settings. By including conceptually integrated and representationally congruent designs in popular commercial games, it just might be possible to make Mario as useful as the Turtle.

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Constructionist Discussions With and Around Microworld Referable Objects

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Abstract

This demonstration highlights design features that are derived from the requirement of enabling discussions around constructionist artefacts. We present the integration of a microworld and a tool for structured discussions resulting in an environment that allows students to share, discuss, critique and ask help about their work in the microworld. The paper summarises the learning environment, its innovative features and how it supports constructionist activity.

Keywords:

microworlds, referable objects, collaboration, discussion

Introduction

Technological advances are making collaborative problem solving and co-construction of knowledge possible even for remote participants. Commonly-available tools for working and learning together range from collaborative editing of documents to controlling and manipulating shared spaces. Notable examples specific to learning include dual-spaces such as the one provide by the Virtual Maths Teams (VMT) project that integrates a chat with a shared graphical work area (Muuhlpfordt & Wessner, 2009). In parallel, research has demonstrated that focused collaborative computer-supported argumentations and discussions promote learning and enhance students' argumentation. Justification and reasoning skills help even co-located students make their thoughts and contributions explicit. State-of-the-art argumentation and discussion tools go beyond simple chat or threaded forum interfaces to provide a shared graphical representation of discussion (see a review in Scheuer et al., 2010 and examples on page 4).

We are interested in exploring the possibilities afforded by the integration of microworlds with such collaborative environments in order to provide unique learning opportunities that are closely aligned to the emphasis constructionism puts in the social element of meaning generation activities (c.f. Resnick, 1996 that introduces the notion of 'distributed constructionism' and three activity categories of *discussing*, *sharing* and *collaborating* on constructions). Supporting such activities is challenging both from a pedagogical and technical perspective. While research is underway to identify both the appropriate pedagogy and the potential of such possibilities, in this demonstration we present our first steps towards an integrated environment that provides a space that encourages students to discuss, argue, seek and offer help about microworld artefacts.

Our prototype tools revolve around a microworld for algebra and a discussion environment that can accept contributions embedding so-called 'referable objects' from the microworld, with the primary objective of enabling *joint attention* and *mutual engagement* — key aspects of successful collaborative groups (Barron, 2003). Below, we present the microworld and its referable objects functionality and provide examples of the integration with the discussion environment. We conclude with a brief discussion about the potential of the integrated tools and future work.

The microworld and its 'referable objects'

The microworld

The MiGen project has designed a microworld where 11-14 year old students can construct patterns of repeated building blocks of square tiles and identify their associated algebraic rules (see Figure 1). Underlying this goal, the main objective is to promote students' appreciation of the expressivity of algebra and support algebraic ways of thinking (Mavrikis et al. in press). Due to space limitations we do not describe in detail the microworld here, but it is worth mentioning a key feature: the use of variables the values of which change dynamically to test the structural generality of a model. Fig. 1 shows an example of a student's construction as it appears when shared on a web page (see also Fig 2 that shows part of the actual space of the students' view in more detail). A variable '*n*' represents the number of houses in the model. The model changes dynamically as the variable takes random values thus resulting in an animated model. In order to colour the patterns in the model, students are challenged to specify algebraic expressions that represent the number of tiles in each pattern. Subsequently they define the 'model rule' that represents the total number of tiles in the model in terms of the variable 'n'.

There are several tasks that one can design in this microworld (e.g. tasks with increased complexity of the rules). Previous work (Geraniou et al, 2011) demonstrated the importance of collaborative tasks where students are encouraged to construct a particular pattern but in structurally different ways. This leads to different — but usually equivalent — model rules and encourages discussions among students about their algebraic equivalence or lack thereof.

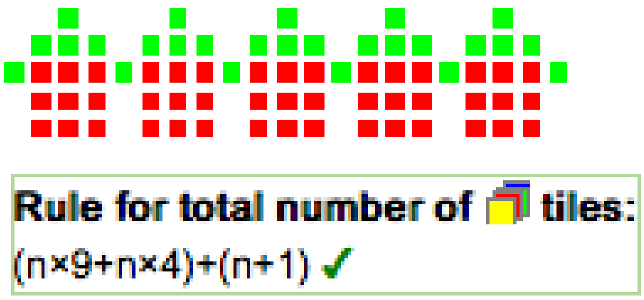

Figure 1. A snapshot of a students' model for n=5 (where n is the number of houses) and the corresponding rule for expressing the total number of square tiles in the model.

Referable Objects

To enable referencing and sharing artefacts from the microworld it was enhanced to allow the creation of 'referable objects' i.e. elements from the microworld that can be viewed as live thumbnails in other tools and can also be accessed in the context of the microworld upon request.

By accessing a menu item, students can share either just their model or their model and their rule. By doing so, a link is provided to a live thumbnail — a web-page that can be embedded anywhere else. An example appears on Fig 1 and, when live, it can be clicked to make the model start and stop animating.

In addition, students can share particular elements (patterns and expressions) of their model. The interaction in the microworld relies generally on contextual menus and therefore when elements are clicked, one of the options provided is to share the element.

Figure 2. Sharing a pattern. By enabling its contextual menu an object of the microworld can be shared.

Discussing with and around referable objects

The microworld is currently integrated in the context of the Metafora project that is developing a computer-supported collaborative learning (CSCL) environment that (among other tools) employs a web-based tool (LASAD) that provides a collaborative, shared workspace where students can share, discuss or argue about certain topics in a structured way (Scheuer et al., 2010). Figure 3 shows an excerpt of an actual discussion map constructed by students when discussing the equivalence of their rules. The tool allows the learning designer (or teacher) to customise the types of the possible contributions and links between the elements of a discussion. For example, it has been used typically to support argumentation between students using "claim" and "fact" boxes with links to "support" or "oppose" them. For the purposes of the activities with the aforementioned microworld, we have developed a template based on constructionist ideas that provides specialised boxes. These boxes can embed referable objects, allow students to ask for help on particular elements of their model, and to refer to key aspects of possible actions with the microworld.

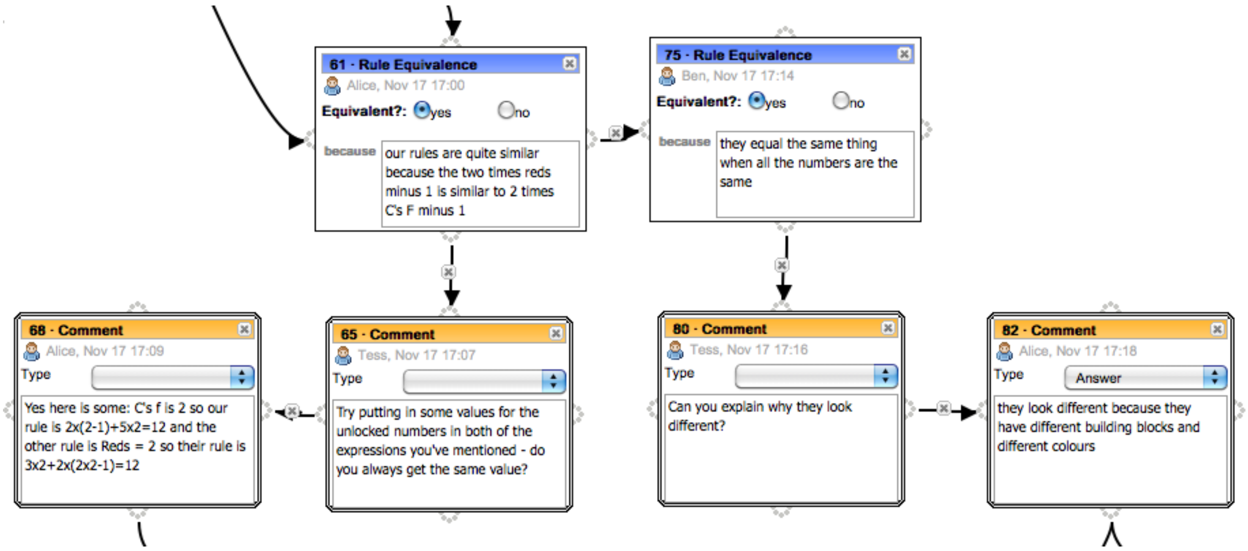

Figure 3. An excerpt of a discussion map. By adding boxes and linking them with each other, students construct maps that can contain several different perspectives. These maps can be constructed both asynchronously to support remote collaboration and synchronously even by co-located participants as a means of externalising their thoughts. The maps persist over time and encourage reflection.

Fig. 4(a) shows excerpts from a discussion using this constructionist template with embedded referable objects. The "My Microworld" box acts as a container for Ben's shared model and rule. The box has a drop-down list for the type of contribution he is making (in this case an "example" of a solution to the given task). The structure of the box also encourages him to provide a short description of what he is sharing. The same figure shows Alice's contribution as she asks for clarifications on the rule. Figure 4(b) shows an example of a *Help Request* that gives students the space to ask for help regarding specific elements of the microworld, and prompts them to explain the difficulty they are having. In this case a teacher (Tess) observes their interaction and asks a question and offers a comment. Other boxes provide the possibility to contribute by choosing particular microworld actions from a drop-down list and, for example, to suggest to *find a relationship* or to *change, observe, define, crosscheck, repeat*, or *reproduce behaviour*.

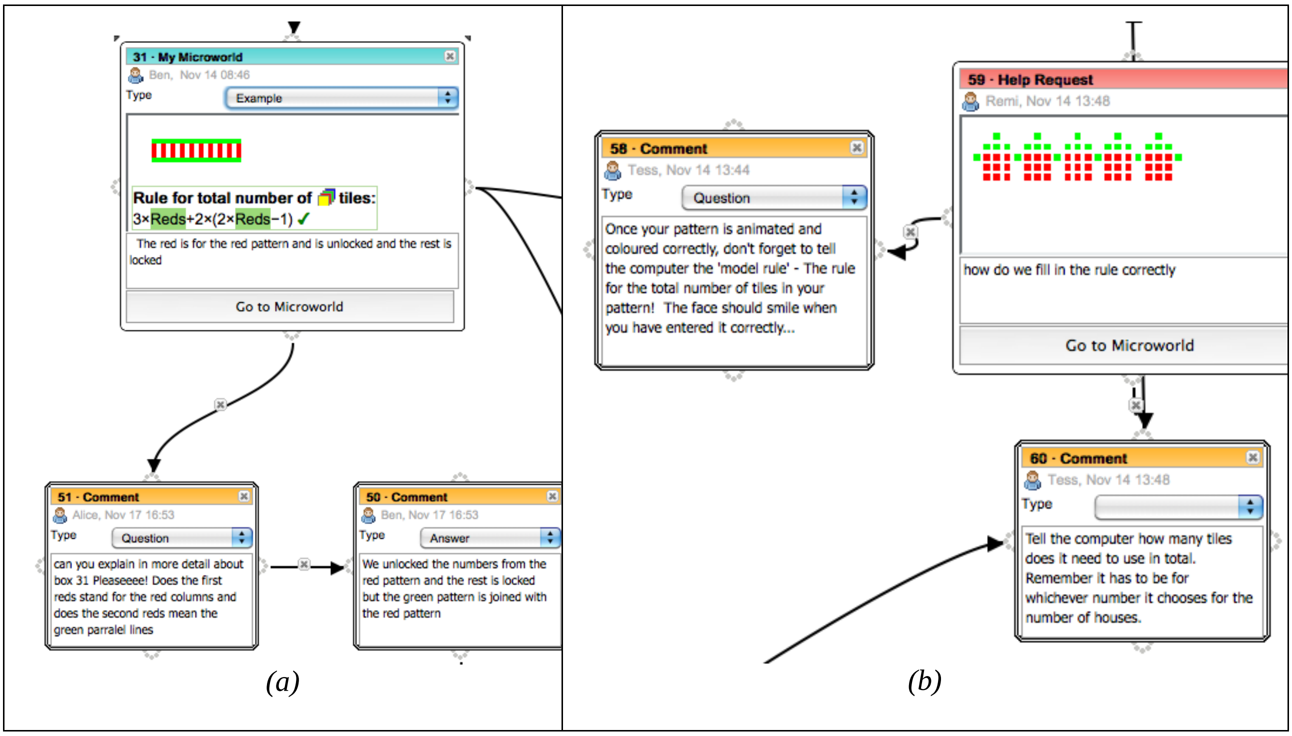

Figure 4. Excerpts from a discussion map with embedded microworld objects. In (a) Ben (Box 31) is sharing his model and offers a description on which Alice asks for clarification (Box 51). In (b) Remi is requesting help for his model (Box 59). A teacher (Tess) who is observing the dialogue remotely is able to support him (Box 60). Clicking "Go to Microworld" allows the participants to see the referable object in its original context of the microworld itself.

Discussion and Future Work

The design presented here describes the early stages of a larger design-based research experiment. The prototype integration of the microworld and the discussion space allows referencing objects as a means of establishing joint attention (c.f. Stahl, 2009) and has the potential to satisfy a key requirement of collaborative learning; mutual engagement (c.f. Sarmiento-Klapper, 2009; Barron 2003).

We have observed in pilot studies how students bringing individual work into the collaborative discussion space can encourage not only sharing individual artefacts, but also seeking and offering help. For example, student with better understanding from others can provide support by sharing particular examples (a form of peer tutoring). In addition, elements from the microworld and particularly expressions become elements of students' justification efforts. Lastly, by offering a space to compare and discuss their artefacts and by allowing the outcome to persist over time, students can reflect both on their actual domain and microworld-specific interaction as well as their collaboration process itself.

As development continues, design questions remain. One example is identifying (in a user-centred fashion) what should happen when a collaborator follows a referable object that has changed since it was originally shared. As shown in Fig. 4 a live snapshot of the state of the microworld is provided at the time of creation. Although it is possible to provide an up-to-date snapshot as it is changed, we consider it important to maintain the history of the discussion as it evolves. By clicking "Go to microworld" we have the ability to provide access either to the historic instance of the model at the time of sharing or the latest version. This raises questions such as: Should the provided model be editable? If the historic instance is editable, what should happen to subsequent edits and how could they be maintained, represented and shared? At the time of this writing, when a referable model is accessed but has changed since it was shared initially, the user is asked to choose whether they want to access the original state (and essentially branch out if they make edits) or to access the latest state (with the caveat that a referred object could be missing). The implications of this complex interaction remain to be tested. Another set of design questions relate to an interface for allowing flexibility in the choice of discussion maps. Our current approach relies on predefined sets of maps where the referable objects eventually appear automatically. In the integrated Metafora system[1], however, we are looking into the possibility of user-defined maps that serve different purposes for example, offering distinct spaces for comparing models or others for requesting help.

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[1] Metafora is an EU-R&D project "Learning to Learn Together: A visual language for social orchestration of educational activities" (EC/FP7, Grant agreement: 257872).

An Online Setting for Exploring, Constructing, Sharing and Learning Mathematical Ideas

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Abstract

We present here an on-going research project on mathematical learning through a process of building math models in a context of rich experimentation and virtual collaboration in an online environment. Our design ideas aim to 1) harness the potential of technological tools for exploration, discovery and learning; 2) use the Internet and social networks as a means of virtual communication and collaboration. Although online distance education is becoming more prevalent, this type of virtual collaboration for learning hasn't yet been exploited much in our country (Mexico). We present the fundamental design of our setting, research objectives and sample activities.

Keywords

Technology-enhanced learning, mathematics, collaboration, constructionism, distance education

Introduction and research objectives

For the past couple of years, we have been working on building an Internet-mediated laboratory for experimentation and virtual collaboration, in which students can explore mathematical problems. Sciences such as physics, chemistry, etc. depend on research carried out in laboratories; but in mathematics, research is done through an idealized world where the tool for discovery is intuition (Klarreich, 2004). Thus our objective has been in developing and researching a virtual setting (an "online lab") where technology is used in a two-fold way: as a tool for local experimentation; and as a vehicle for communication and collaboration.

We present here parts on-going study that aims to investigate how students can explore mathematical ideas through experimentation and virtual collaboration (via a social network), which may lead to insights and discoveries that can be more difficult through traditional media. The main purpose is to encourage students to make discoveries and build knowledge, following the constructionist paradigm (Papert & Harel, 1991), in a technological environment that is conceived as a research laboratory where, through computer programming and construction (which can involve processes such as trial and error, debugging and feedback) learning can be enhanced (see also Hitt, 2003; or Sacristán et al., 2010). Online blogs and social networks are used so that participants can collaborate on a task or set of problems related to a particular topic, sharing their ideas, knowledge and expertise.

It is remarkable how thirty years ago, Papert (1980) had already proposed that computer microworlds could be used in this way and for constructionism. Nowadays, the affordances of digital technologies are more powerful and readily available, in particular allowing virtual collaboration and communication. In spite of the growing tendency in the use of virtual settings in education, "constructionist online collaboration" is still rare; thus, we believe that the potential of virtual collaboration, as such, can be exploited much more in education and may be attractive to students in all levels who are already immersed in the dynamics of social networks. For this, we have designed a web-based educational platform that has, as basic elements, tools for collaboration, communication (including a discussion forum and blogs) – see Figures 1 and 2 – and a repository of various types of documents (e.g. tasks, programming activities, images, videos sharing, the activity software files, etc.).

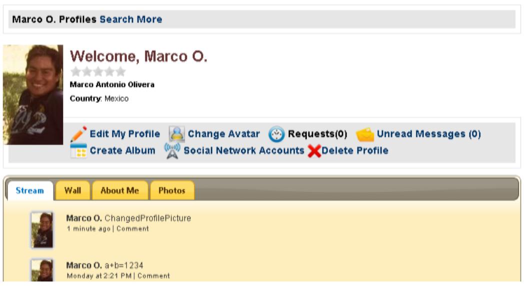

Figure 1: Social network tools of the virtual setting

Figure 2: Portal to one of the explorations on the platform including to its forums and blogs

As already stated above, in our project, we use technology as a tool for exploring and constructing mathematical ideas; and as a tool for communication and collaboration. The key objectives of our study are thus twofold: 1. To encourage experimentation, collaboration and reflection of mathematical problems among virtual community members. 2. To analyze how these processes can promote learning in the participants. This analysis includes looking at the role of the computational and ICT tools in the development, exploration and learning of the mathematical ideas studied in the virtual environment; what thinking processes and attitudes are developed; but also what difficulties are encountered in the execution of the virtual collaborative activities.

Background and theoretical framework: Constructing, sharing and learning

As stated above, our main theoretical principle is the constructionist paradigm. Thus, we define our virtual exploratory environment as a place where one can create, execute and disseminate mathematical experiments across a computing infrastructure consisting of a set of programmable objects. Jeschke, Richter & Seiler (2005) define the concept of a virtual laboratory in mathematics and social sciences as a set of interactive tools that achieve learning through exploration. Some authors, such as Schmid et al. (2001), have designed virtual labs where they can perform simulations, interactive animations, and experiments. Other studies, such as those of Hoffman et. al (1994) and Sánchez et. al. (2002), combine laboratory experiments with computer simulations and experimentations that involve the manipulation of various physical tools controlled remotely via a web platform.

In our study, the context in which the mathematical activities take place, as well as the social forms of interaction, are as important as the tasks themselves (Hoyles & Noss, 1987). Thus our activities take place in a type of social network, where participants can share a concern or set of problems on a topic and deepen their knowledge and expertise through a social structure based on collaboration – akin to what can happen in Wenger's (1998) communities of practice. In other words, the key aspect is a collaborative learning strategy: a carefully designed system to organize and lead the interactions between team members (Johnson & Johnson, 1997). Collaborative learning is developed through a gradual process in which members can feel mutually committed to the learning of others, creating a positive interdependence not involving competition (Lucero et. al, 2003; Crook, 1998; Johnson & Johnson, 1997). In our project, most of this collaboration takes place virtually.

It is worth noting that a main inspiration and background study for our research was that of the WebLabs project, which was a European research project in mathematics education involving schools and research institutions in six countries. In that project, a community of students, teachers and researchers worked collaboratively exploring mathematical ideas and scientific phenomena through computational and virtual infrastructures (see Matos et. al. 2003; Sendova et al., 2004; Kahn, 2004; Mousolides et. al, 2005; Simpson, Hoyles and Noss, 2005; Mor et al., 2006). The aim of Weblabs was to investigate new representational infrastructures for constructing, sharing and learning mathematical and scientific ideas. Since the design and conception of the WebLabs project, included many of the same theoretical and methodological ideas that we support (such as a constructionist use of technology, and collaboration in virtual communities), we have used it as a basis for our research.

In terms of the mathematical explorations and tasks, many these are conceived to promote learning through the building of models. What is meant by modelling? This can be understood in several ways. First, it can be understood as the construction of a mathematical model, thus bridging real world phenomena with the mathematical world:

> Mathematical modeling is a process of representing real world problems in mathematical terms in an attempt to find solutions to the problems. A mathematical model can be considered as a simplification or abstraction of a (complex) real world problem or situation into a mathematical form, thereby converting the real world problem into a mathematical problem. (Ang, 2001, p. 64)

But modelling can be used, not only to "find solutions" but, as Epstein (2008) emphasizes, to *explain* phenomena. Therefore models and their representations can be of different levels of complexity and/or accuracy (i.e. more mathematically-dependent or less). Lesh and Doerr (2003, p.10) explain that: "Models are conceptual systems … that are used to construct, describe, or explain the behavior" of a system. Thus, modelling is a powerful tool that can enhance the principles of scientific thinking (Aris, 1994). That is, creating one's own models can be a powerful learning experience that can help to better understand the world around us. Digital technologies have provided a new medium for building, analyzing, and describing models; they make it easier to build and explore one's own models and learn new scientific ideas in the process (Colella, Klopfer, & Resnick, 2001). One example of the possible constructionist nature of modelling real world problems, and of its potentials for learning, is described by Noss and Hoyles (1996) in relation to computer-based tasks related to modelling the mathematics of banking:

> Throughout the work, our students constructed and reconstructed the resources we provided, and explored and expressed regularities and structures they encountered. We gave them the simple programs as building blocks, but they edited them, switched variables and parameters, and recombined these blocks to model financial situations, some of which were strange to our eyes […] the mathematical and banking ideas came to be woven together to produce a powerful synergy, making both the mathematics and the structures of banking practices more visible. The power of the computational modelling approach was that it facilitated this interconnection: students could

> interlace their banking knowledge with the mathematical ideas we intended to teach and in the process take control of the direction of their investigations. (Noss & Hoyles, 1996, p. 29)

Lesh and Doerr (2000) claim that some of the key components involved in models and modelling are symbolizing, communicating and mathematizing. We want to exploit these in our project so that the tasks in our online lab provide our students with the opportunity to engage in activities as mathematicians (Papert, 1972): by symbolizing ideas in the problem, sharing and discussing their findings with peers, and refining their proposed model.

The mathematical activities

We have currently been designing exploratory activities for high-school and university students (although in later phases of the project we would like to also work with younger students). In the design of the activities, we have been concerned on how to design thematic lines or mathematics explorations to enhance motivation and continuous reflection through the virtual environment. We have thus been concerned with two things: the mathematical ideas to be studied; and how to carry out the explorations of those mathematical ideas. Therefore, we have been designing computer-based exploratory hypothetical learning trajectories (Simon, 1995) of several mathematical topics (e.g. see Figure 3); the topics we have chosen are such so that they have the potential to generate several problems for analysis, and may promote discussion among members of a virtual community allowing in turn for the emergence of new issues to be analyzed. Some of the explorations topics we have been working on, are: uniform rectilinear motion with cars; cryptography (decoding hidden messages using frequency statistics); and the population growth of spotted owls. For the explorations, we draw from a variety of technological tools (depending on the activity) to explore ideas and build models, including Modellus (see below), Logo, NetLogo, Excel and e-Slate. We present below some sample activities from our study.

The Population of Spotted Owls[1]

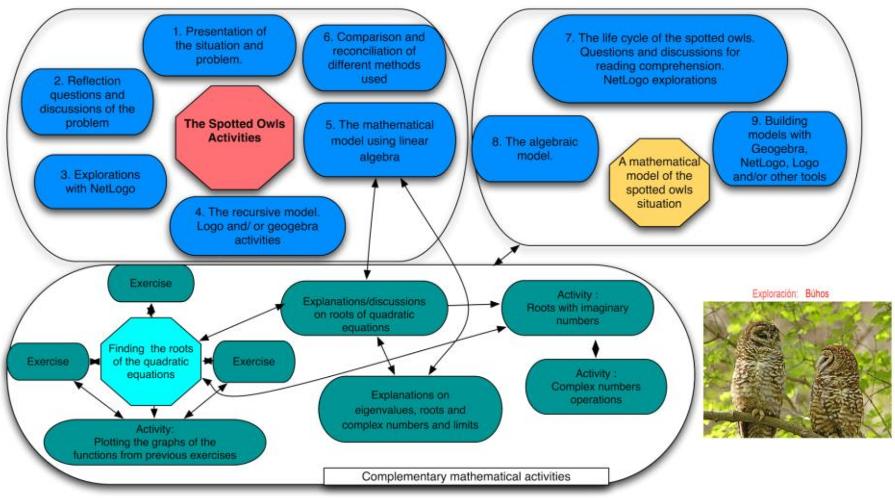

Figure 3: Schematic of the owls' population activities and learning trajectories

The details of this exploration are beyond the scope of this paper, but we include some of them

[1] We thank Juan Carlos Torcuato for his work on this activity.

here because this is a real-life problem that can be used to introduce students to many mathematical topics, but is, particularly, an example of a use of complex numbers. The mathematical model[2] centres on a system of recursive equations involving populations of rats and owls, where O_k is the owl´s population at time k; R_k is the rat´s population at time k; and p is an unknown positive number:

$$O_{k+1} = (0.5)O_k + (0.4)R_k$$
$$R_{k+1} = (-p)O_k + (1.1)R_k$$

Time (months)	Owl´s Population (O)	Rat´s Population (R)	Rate (Rat´s population /Owl´s Population)
1			
2			
3			

Table 1: Populations of owls and rats through time

One of the first tasks is to fill a table (similar to the one shown in Table 1) that can help students – using the NetLogo (http://ccl.northwestern.edu/netlogo/) multi-agent programmable modelling environment – modify, as necessary, a Population Dynamics program to do a simplified model of this Owls and Rats situation. In order to properly solve the set of equations, linear algebra is required (leading to a solution involving complex numbers). So this is an opportunity to introduce themes of linear algebra to students, through the eigenvectors and eigenvalues of the matrix:

$$\begin{bmatrix} 0.5-\lambda & 0.4 \\ -0.104 & 1.1-\lambda \end{bmatrix}$$

Or, at another level, through the following matrix equation, where J_k is the female population of very young owls in the k time; S_k is the is the female population of middle age owls in the k time; and a_k is the female population of old age owls in the k time:

$$\begin{bmatrix} j_{k+1} \\ s_{k+1} \\ a_{k+1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0.33 \\ 0.18 & 0 & 0 \\ 0 & 0.71 & 0.94 \end{bmatrix} \begin{bmatrix} j_k \\ s_k \\ a_k \end{bmatrix}$$

The Free Fall explorations

The Free fall activity (which is a much-exploited activity in mathematics and science education) is intended for exploration of the movement of an object being dropped down. The purpose of the activity is for students to construct a mathematical model to express the relationship between time and height, such as the equation $h = \frac{1}{2}gt^2$ where h is the height, t is the time-interval, and g is the gravity constant. The explorations use Modellus, a free software from Portugal (http://modellus.fct.unl.pt/), for which we provide a link on our platform. Students have to record a video of the free fall of a ball (or other object), using a video camera, upload it unto the Modellus system, and analyze the mechanics of the experimental data, first locally, on their own computers, and then through virtual collaboration (see below). The Modellus software allows for analysis of the distance from the origin and the floor, at different time intervals (see Figure 4), so

[2] Note: this model does *not* involve, in the beginning stages, the Lotka–Volterra predator–prey equations.

that the speed in each interval can be inferred, and eventually they might discover that there is a constant (the gravity constant).

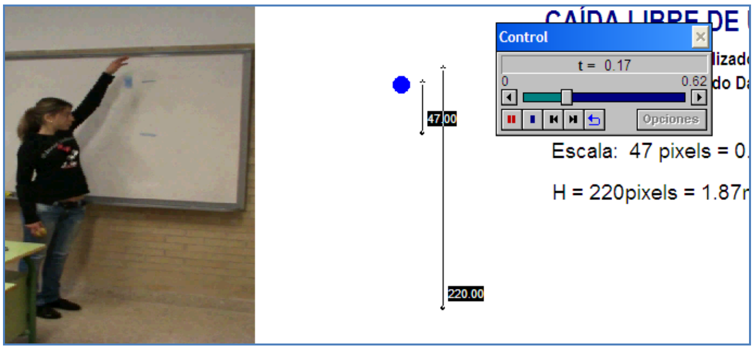

Figure 4: Analysis, using Modellus, of a person dropping a ball.

Figure 5: Blog of the "Free fall" activity.

On the platform we provide a worksheet with reflection questions regarding the activity, as well as suggestions of different working tables; using the questions and tools on the worksheets as guidelines, students then write down, on a blog (Figure 5), their inferences about the phenomena derived from their explorations using the software; they can add their videos, files and screen captures. They can then participate in online virtual collaborative discussions, sharing ideas and analyzing each other's data and conclusions, in order to refine their individual models and construct a collaborative model of the phenomenon

In summary, the purpose is for students to collaboratively build a mathematical model of the free-fall phenomenon, through a hypothetical learning trajectory that involves processes of: getting data, discussing their findings through the blog, the forum, when possible video-conferences, and then test their model using the Modellus software; this is a cyclical process until a mutual agreement is reached on a mathematical model that best describes the phenomena, and finding the gravity constant. This activity is followed by a second activity to discover the gravity constant on the Moon, by analyzing videos of a man jumping on the Moon.

The Moving Cars explorations

The Moving Cars activity is intended for students to explore linear motion with constant speed, and model it through a mathematical process of experimentation. The phenomenon of uniform rectilinear movement encompasses a wealth of mathematical ideas to be explored and experimented by students, and yet is a real phenomenon that can be modelled using basic equations. For this activity we also use the Modellus environment.

The tasks in this activity are of two kinds:

- Initial exploration tasks, proposed by the teacher.
- Open exploration tasks proposed by the students.

The first group of tasks is intended to provide students with the intuition of "uniform rectilinear motion with constant velocity". For this, we start from different situations: A first situation is given by providing a Modellus model (see Figure 6), with two moving vehicles that begin their journey at the same time with different speeds (for example, car A has a speed of 5 km/hr, while car B has a speed of 7 km/hr).

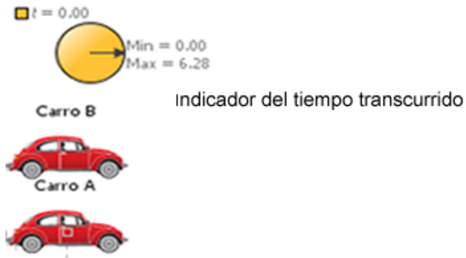

Figure 6: Exploration of the movement of two cars with the Modellus software

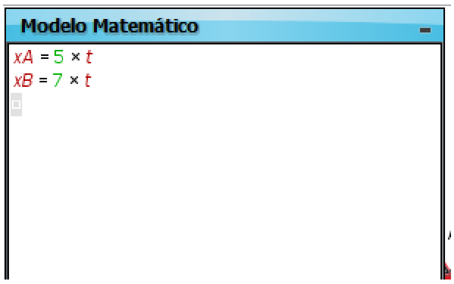

Figure 7: Defining the mathematical equations of the distance covered by each car

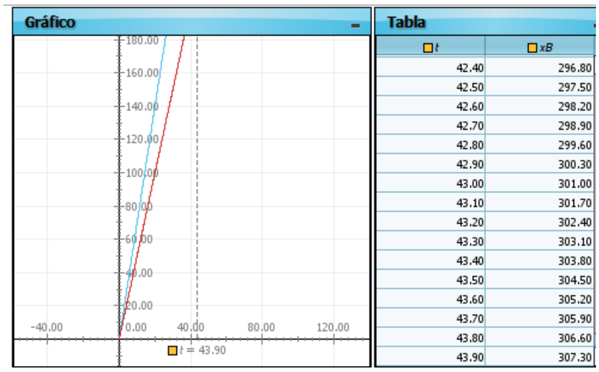

Figure 8: Graph and table of the distance covered in function of the time

Students can define the mathematical equations of the distance covered by each car, as shown in Figure 7. In Modellus they can also build a table of distance covered by each car in function of the time (see Figure 8). Some of the explorations that are suggested refer to the question: After how long will the vehicles be separated by an x distance (for example, by 80, 90, or 150 miles)? To answer this, students must manipulate the mathematical objects, define new mathematical equations by creating another variable which measures the distance between objects, and, at a higher level, solving an equation. During the explorations, they can use exploration tools, such as the one to measure distances (see Figure 9), or the one (see Figure 10) for defining distances (a function) by parts (see Figure 11).

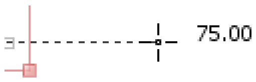

Figure 9: Modellus tool to measure distances

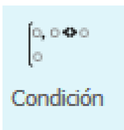

Figure 10: Modellus tool to define a function by parts

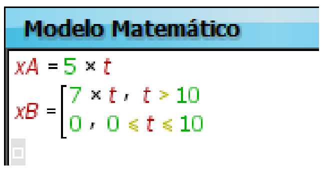

Figure 11: Distance defined by parts, considering time intervals

The second group of tasks (those proposed by students for other students) is intended for students to explore their own ideas and socialize with their peers, thus promoting collaborative work. Some ideas for this, include students proposing a graph to other students (over the virtual platform), and asking the other students to find/build a model or mathematical equations that fits the graph; or viceversa: proposing the mathematical equations of the model and then asking their peers to describe a situation that fits these.

Methodological aspects and preliminary results

Currently we are working with a learning community that consists of 60 adult continuing education students enrolled in a distance (online) open university system (www.abiertayadistancia.sep.gob.mx – launched two years ago by the Mexican Ministry of Education), studying towards a degree in Mathematics. These students are finishing their second year of studies, and constitute a very mixed community of students of all ages and backgrounds and are located in different parts of the country. These are subjects who are, to some degree, familiar with self-study and with the use of different tools used in distance education, such as a learning platforms and forums, etc, since the distance university system is based on Moodle. However, for our study we chose not to use Moodle since we found it limited in terms of social networking capabilities and for virtual collaboration; we thus have our own platform (http://imat.cinvestav.mx).

One of the approaches for the data analysis is based on the documentary approach proposed by Gueudet and Trouche (2009) who consider that the analysis of documents (which in our case are all of the participants' contributions on the virtual platform: e.g. comments on forums; messages – which include written interviews from our part; blogs; development of computational objects or codes; approaches to the problems; etc.) should consider the following components: the material component (i.e. the set of resources used in the educational activity), the mathematical component (the concepts and activities involved the study) and the dialectical component (which includes the organization and planning of the activity).

So far, 27 of the 60 students (with an interesting age range from 20 to 70 years old) have volunteered to take part in our study, with more signing up every day. We have divided these students to participate in the different activities. A first group, consisting of 6 students, have been working on the Moving Cars explorations. Below we give some initial findings from this group.

First, there were initial difficulties in the proposed collaborative and exploratory model of working, because this is very unusual in the Mexican educational system. Participants are thus used to simply following detailed instructions from a teacher, solving some activities individually and expecting a grade. To collaborate virtually, was even stranger for them. So one of the first obstacles was for them to understand this new working paradigm and that it wasn't "solving a problem that would be graded". However, gradually the participants have been getting used to the activities and began engaging first in discussions on what it means to build a mathematical model. Through these discussions they identified (as a virtual group) that there have to be elements such as variables and equations that describe a mathematical model; and, individually, they began building their models in Modellus, such as the case of Judy who published in her individual blog on the platform, an image of her model (Figure 12).

There also had discussions on the forums in relation to the concepts of speed and velocity, as well as on the meaning and interpretation of the graphs. Thus we are beginning to see good results from the virtual activities in the sense that there is collective reflection and discussion on the meanings of the activities, concepts and elements involved. A student also proposed a model for the use of a taxi, involving distance, time and cost; this has also led to discussions among the members. Work continues and we hope to achieve further positive results and meaningful learning and constructions.

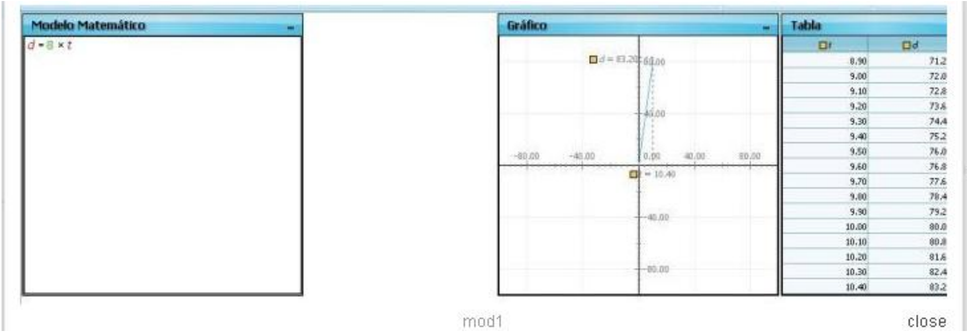

Figure 12: Judy's first model in Modellus

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My Interactive Garden – A Constructionist Approach to Creative Learning with Interactive Installations in Computing Education

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Abstract

In this article the question is pursued, how developments in interactive computing systems can be harnessed to strengthen constructionist learning in computing education. Based on an analysis of interactive computing systems, My Interactive Garden provides a concept for motivating principles of computing including a construction kit, activities and examples that may empower students to create meaningful interactive objects.

Keywords

Constructionist learning in Computing Education, interactive computing systems, Arduino

Introduction

With the Logo microworld and the corresponding constructionist approach to learning Papert (1980) introduced a sound concept to learning, especially in mathematics, that in the following years had a tremendous impact on learning in other subject areas as well. Especially teaching and learning of principles of computing in primary and secondary education, e.g. programming, until today very much rely on the ideas of Papert. Microworlds and virtual interactive robots are commonly used in introductory courses. As such, tools like Kara (Hartmann, Nievergelt, & Reichert, 2001) and Karel the Robot (Pattis, 1981) provide early experiences in programming to students in computing education. However, criticism of these tools often refers to a lack of tangibility, a lack of creativity and an outdated understanding of what programming or computing really is about. Even with the further development of Logo, e.g. Lego Mindstorms, creative possibilities are limited. Also, it seems to be difficult to increase female participation in Lego Robotics activities (cp. Resnick, 2007).

Due to the technical developments within the last years computers are no longer considered as machines that merely receive and act on orders, but as interactive and ubiquitous media. This development of interactive computing systems can be used in order to address the above-mentioned issues. Corresponding projects have been used successfully in primary education (e.g. with Pico Cricket, cp. Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). With the concept of *My Interactive Garden* this trend shall be seized and adapted for computing education by pursuing the question how developments in interactive computing systems can be harnessed to strengthen constructionist learning in computing education. The question is addressed with the analysis of recent progress in interactive computing systems and by integrating the findings into a constructionist approach for learning fundamental ideas of computer science. As a consequence, a constructionist learning environment is proposed, which focuses on creative learning, supports motivation and leaves the pure virtual world by offering to design tangible interactive objects for ubiquitous media installations. In this way, a constructionist approach can be applied at all levels. It makes an elementary introduction to physical computing possible, but also the sophisticated application and programming of microcontrollers with advanced tools. Additionally, this approach allows for providing a more appropriate notion of computer science as a multi-facet discipline by motivating questions of theoretical concepts, hardware aspects, applications of computing devices as well as referring to influences of and on society.

In chapter 2 the state of problems in the context of constructionist approaches to learning in computing education will be discussed. Chapter 3 scrutinizes the perspectives on interactive computing systems for their relevance for computing education. The findings are integrated into the concept of *My Interactive Garden*, which is elaborated and illustrated in chapter 4. Finally, the concept and its prospects are discussed in the context of classroom demands and experiences.

Constructionist Approaches to Learning in Computing Education

First comprehensive reports about constructionist learning in primary education with the Logo programming language date back as far as the 1980s (e.g. Hoppe & Löthe, 1984, Ziegenbalg, 1985). The intention was not primarily to teach principles of computing but to allow learners to explore and understand mathematical and geometrical structures in a constructionist way. As Papert argues, “[learning] happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe” (Papert & Harel, 1991). Hence, the construction of knowledge is based on an active construction process. In such a way a meaningful artifact will be created, which the learner can try out, show around, discuss, analyze and receive praise for. It is the examination of such an artifact that leads to the understanding of a particular phenomenon. Microworlds describe computer assisted learning environments in which such learning can happen unhindered by the complexities of the world (Papert 1996). This approach was adopted for computing education: Various microworlds by now are used in classroom, e.g. for learning programming (Karel the Robot, Pattis, 1981) or for offering a more motivating approach to theoretical concepts, such as finite state automatons (e.g. Kara the ladybug, Hartmann et al., 2001). However, such microworlds receive criticism for fostering an inappropriate and possibly unattractive notion of computing, which is not primarily concerned with moving robots or lady bugs through labyrinths. Additionally, these microworlds seem to violate the underlying ideas of Logo: Empowering the learner to create a personally meaningful product. Instead, the corresponding exercises of Karel, Kara and similar learning environments pose unauthentic and often merely algorithmic problems (cp. Romeike, 2008). In such contexts constructionist learning can barely happen.

Lego Mindstorms transfers the idea of Logo and Microworlds into the tangible world. Due to the possibility of making programs “come to life” it is used widely in computing education (e.g. Wiesner & Brinda, 2007). But criticism of Lego Mindstorms points out that such constructions can easily become complex, have to cope with a variety of mechanical problems and hence are difficult to achieve, especially for younger children. Also, even though it is possible to create a variety of constructions with Lego Mindstorms, mostly robotic vehicles are built (ibid.). Thus, in educational contexts, it is difficult to address a broad range of interests. As a consequence Lego Robotics is mostly used in non-formal educational settings, such as school clubs and workshops. By analyzing the outcomes of a Girls Scout workshop series over several years Guzdial (2010) found that activities with Lego Robotics did not lead to a positive attitude towards computer science significantly. However, interest of the participants and subsequently a positive notion of computer science were determined after activities with Scratch and Pico Cricket. Pico Cricket is a construction, programming and learning environment that connects constructionist learning with the tangible world. Its creations can be touched, shown to others, be played with and more. Pico Cricket may be a good way to start with in computing education in primary school, but the system is too trivial for secondary education. Also, for a broader dissemination the available sets are too expensive, difficult to order and break too easily. Even though Pico Cricket was already introduced in 2006, until now it is hardly used in computing education (at least in Germany). Instead, more and more approaches focus on using the Arduino platform (see chapter 3). For the above-mentioned reasons the concept of *My Interactive Garden* builds on such a platform, which is customizable, reasonable, but can be programmed in a variety of ways and is adapted in a way that it is as easy to use as Pico Cricket.

Interactive Computing Systems

Nowadays computing systems have integrated into everyday life. They are no longer perceived as mindless machines that receive orders and act accordingly, but as intelligent devices, which ease and enrich people's lives. Interactive computing systems are based on various innovative ideas such as embedded systems, ubiquitous computing, physical computing and interactive installations. This should become apparent in computing education. Recent developments in this field will be analyzed. The findings shall then be integrated into a constructionist approach for learning fundamental ideas of computer science.

Embedded Systems

Embedded systems pervade nowadays life. Many of the technical artifacts that are used every day contain an embedded system in some way. Due to its importance, this phenomenon can also be called pervasive computing (Weiser, 1991). Embedded systems can be described as "a combination of micro(s), sensor(s), and actuator(s) designed for some specific control function and 'embedded' into a specific device, usually requiring little human input. An example would be the air/fuel mixture control system in an automobile engine" (Pardue, 2010). Thus embedded systems perform single, straightforward tasks, in comparison to personal computers, which are expected to interact with humans and perform a broad variety of tasks. Robotics can be classified as intelligent embedded systems, which integrate hard- and software in one system, but are capable of performing tasks that rely on mechanical actions. Hence, robotic systems are often found in industrial environments. Typical constructionist tools for teaching, such as Lego Mindstorms and Pico Cricket can be classified as tools for creating embedded systems. Even though youth gets in touch with embedded systems on a daily basis, only few have the possibility to create their own embedded system and understand the functionality, potential and limits of such devices.

Ubiquitous Computing

In 1993 Weiser already described his vision of new hardware systems that should be developed for something he called ubiquitous computing: "Ubiquitous computing enhances computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user" (Weiser, 1993). The ideas of embedded systems and ubiquitous computing are closely interrelated. Without embedded systems ubiquitous computing would be impossible. The overall idea is to enhance the usability and efficiency of computers and, at the same time, make them invisible by integrating the systems completely into everyday life. If computers do not stand out anymore, comparable to electricity, the vision succeeded (West, 2011). Weiser sees therein an about-face of computer science: "But it is a start down the radical direction, for computer science, away from emphasis on the machine and back on the person and his or her life in the world of work, play, and home" (Weiser 1993). For computing education this is a very attractive perspective to learn and discuss computer systems, their capabilities and their limits, but also to invent and create computing artifacts that follow this idea. Typical products of ubiquitous computing are keys that send their position when lost or self-regulated lighting, as opposed to notebook or tablet computers, which are portable, but do not "understand" their environment and act appropriately. In educational settings ideas of ubiquitous computing have been especially used in the context of "Wearables" (e.g. Martin, 2003, Resnick, 2007) and in higher education (e.g. Richards & Smith, 2010) where students have created useful devices, such as weather stations, based on their personal interest. The design of such devices may serve as a challenging task if creatively generating ideas and finding solutions to particular problems, where ubiquitous computing is useful.

Physical Computing

Physical computing is an activity that increasingly received attention within the last years, especially by non-computer scientists, such as artists and designers. The idea of physical computing is to use programmable hardware for creating interactive physical systems. Since these systems use sensors (e.g. for noise, light, cp. chapter 4) and actuators (e.g. motors, lamps, cp. chapter 4) they are capable of sensing and responding to the analog world, thus helping to investigate and redefine the relationship between humans and the digital world (cp. O'Sullivan & Igoe, 2004). Due to its creative potential, artists and designers use techniques of physical computing for handmade art or interactive installations. This is an opportunity for computing education to use the interrelations between art and computing in order to increase the attractiveness of the subject. Physical computing promotes prototyping with electronics, which leads to tinkering with ideas of computing (cp. Banzi, 2011). Summarizing, physical computing is the design and creation of interactive objects. This idea perfectly matches with the primary idea of constructionist learning, which has the creation of personal meaningful artifacts in its core. These artifacts may now become interactive.

Arduino

Physical computing requires a microcontroller, which can be programmed to control a variety of sensors and actuators. The hardware with the largest prevalence and the most active community at the moment is *Arduino*. Arduino boards are microcontrollers, which exist in different shapes for different purposes. They all have in common that in addition to in- and output pins they consist of microprocessors and flash memory and offer the possibility for external power supply. Arduinos do not require a permanent connection to the computer and are therefore, but also because of their small size, suitable for embedding into interactive objects. Extending Arduino boards with particular shields offers the possibility of customizing the board and e.g. adding WiFi or Bluetooth functionality to the microcontrollers. This way, changes in programs can easily be made without deconstructing the whole object. This also allows controlling an object with mobile devices such as smart phones or tablet computers. The use of Arduino offers nearly unlimited possibilities concerning the choice of sensors and actuators. The large variety of components also allows to easily and inexpensively construct spare parts and upgrade an Arduino construction kit.

Interactive Objects in Interactive Installations

Interactive installations may form a constructionist approach to computing education that combines the goals of teaching principles of computing with the ideas of embedded systems, ubiquitous computing and physical computing. Students are encouraged to follow their own interest by realizing various ideas, whether they are stemming from arts, music, technology, or everyday life.

Rusk et al. (2008) describe interactive installations in the context of robotics, which comprise "all types of programmable machines that perform actions based on inputs from sensors – everything from a home security system that sounds an alarm when it detects motion to a greenhouse that regulates its temperature and humidity." In this context they suggest the following strategies in order to raise participation:

1. Focus on Themes (Not Just Challenges)
2. Combine Art and Engineering
3. Encourage Storytelling
4. Organize Exhibitions (Rather than Competitions)

In such a way learners are encouraged to not just copy or rebuild systems which they already know but to use their imagination and creativity in order to develop personally relevant interactive objects that can be used in interactive installations.

Interactive Objects are integrated systems containing a miniature computer (microcontroller) that is invisible to the outside world. They perceive their environment with sensors, which in turn deliver data to be processed by the microcontroller. According to the configuration of the systems these data are processed and passed on to the actuators. In this way, interactive objects communicate with their environment. They are created with crafts, art and design material. They fulfill a particular purpose, which may be purely artistic. Interactive objects can be part of networks of interactive installations.

My Interactive Garden

People sometimes dream about the Garden of Eden – a place where things happen right as you desire. The idea of *My Interactive Garden* is to demonstrate that engaging with principles of computing and creating interactive objects can get one closer to realizing a dream. *My Interactive Garden* is the concept of realizing cooperative exhibitions of interactive installations. Such installations consist of embedded artifacts that implement the idea of ubiquitous computing by applying concepts of physical computing with Arduino microcontrollers. Yet, the application of such a concept in educational settings has been difficult due to the complexity of microcontrollers and the limited technical capabilities of existing construction sets for children. With *My Interactive Garden* a construction kit is developed, which reduces the complexity of using and programming Arduino. It allows for immediate tinkering and trial without the need of elaborated skills in physics or principles of electrical engineering, such as soldering. Also, programming of interactive objects in *My Interactive Garden* can be approached in different levels (cp. fig. 2). Hence, staying in the same context while progressing with programming or computing skills or conducting cross-level projects is possible. With Scratch for Arduino (S4A, 2012) in connection with Arduino microcontroller boards already at a low age level immediate tinkering and constructing of interactive objects is possible even for novices. *My Interactive Garden* hence is based on three pillars: constructionist learning, interactive computing systems and thinkering[1]. Students are encouraged to creatively use their imagination in a challenging constructionist learning environment where there is no predetermined way of doing things. They create interactive installations by ex-

[1] Thinkering: A portmanteau of "thinking" and "tinkering". Means to think about something by tinkering with objects relating to the problem under consideration. Usually unguided, exploratory and individual, often a very good way to explore aspects of difficult problems or to find solutions where none are obvious. (www.urbandictionary.com/define.php?term=Thinkering)

perimenting, analyzing and improving their work and methods. Additionally, students are motivated to make use of and find out about computer science concepts they happen to need for their projects.

The Construction Kit

It is the idea of *My Interactive Garden* to provide a construction kit based on Arduino that overcomes the barrier of technical complexity and encourages immediate tinkering. Until now the complexity of the Arduino hardware prevented from such an approach in elementary instruction. Unlike the Scratchboard, Arduino components are not easy to handle, e.g. you need to apply electrotechnical knowledge if adding a button or light because an additional resistor needs to be added to the circuit. It is therefore necessary to develop components that do not require students to solder or to work with breadboards, which quickly gets confusing. Hence, the items of the construction kit are built considering the following principles.

Simplicity: The items are provided with easy to use plugs so that students do not have to handle tiny wires that easily break or slip off the pins on the Arduino.

Flexibility and Extensibility: Sensors and Actuators can easily be added, removed or exchanged. Extension cords are provided to allow students to mount their parts in a distance to the boards.

Black/whiteboxing: Those components that contain circuits of subordinate relevance (e.g. the assembly of a brightness sensor) are hidden in a black box. However, if intended the black box can be "opened" by recreating such sensors, actuators or boards or by examining the corresponding data sheet.

Emphasize computing principles: Underlying computing principles are visualized, e.g. the IPO model is demonstrated by using separate boards for in- and output.

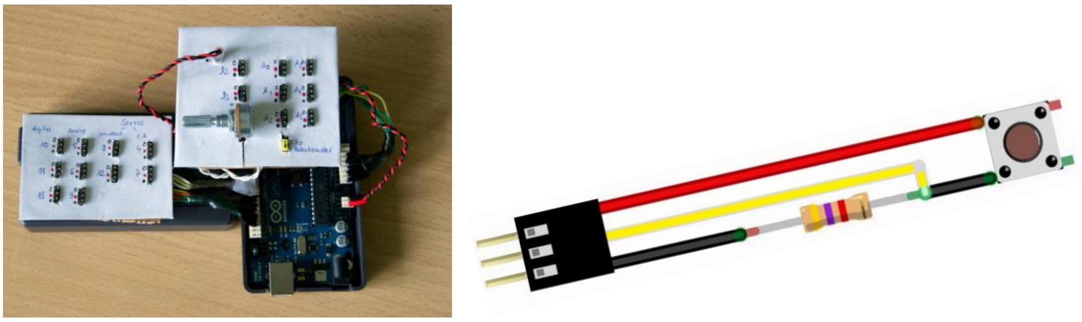


Fig. 1: Left: Boards for sensors and actuators with the Arduino. Right: Circuit of a button.

The construction kit contains the following items:

The Sensor and Actuator Boards

In order to simplify the handling of sensors and actuators on the Arduino and to separate inputs and outputs visually, two separate boards will be used (cp. fig. 1). These can be plugged into a single Arduino microcontroller. The input pins of the sensors and actuators are grouped according to their use in S4A, which is also in line with the use in other programming environments (e.g. ModKit). Arduino boards are not optimized for plugging in pre-assembled sensors and actuators, which makes experimenting more complicated than necessary. With the sensor and actuator boards produced for classroom use, the connectors, which consist of voltage, ground and data pins, are placed next to each other for every in-/output, so that sensors and actuators can easily be plugged in. Color-code labels will prevent users from plugging in components incorrectly.

The Sensors

The sensors are prepared to allow students to plug them in and read their sensing values immediately. Everything but the head of the sensor and the plug will be a black box to the students, e.g. the resistor belonging to the button shown in figure 1 is invisible. As follows, the sensors of the construction kit are described including their technical background and possible uses.

Brightness sensor: A brightness sensor is composed of a light dependent resistor and a pull-down-resistor, which makes it possible to send data to the microcontroller. The resistance changes with the intensity of the ambient light. The darker the environment, the higher the resistance. Threshold values that correspond with particular brightness levels can be used to control actions and actuators.

Temperature sensor: Temperature sensors are very similar to light sensors. The resistance of the sensor changes according to the ambient temperature. When 0°C is measured a value of 0 will be read on the Arduino pin (which means that the resistance is as high as it can be). When 100°C are measured a value of 1023 will be read on the Arduino pin (which means that there is no resistance at all). It is recommended to use average values when calculating temperatures in order to compensate variations in voltage.

Sound sensor: A sound sensor basically consists of a microphone and a preamplifier. To build a good sound sensor many components such as different capacitors are needed. Hence, there are two options: First, a pre-assembled sound sensor can be used. Second, the sensor can be assembled by oneself. Using those sensors depends on what shall be measured. The easiest way is to use them as noise detectors, which means to measure differences to normal ambient noise. This would again imply to determine particular threshold values. In more advanced settings (requiring good sound sensors), particular sounds will have particular patterns. These patterns can be detected, analyzed and used.

Switch and button: The switches used in the construction kit are actually buttons, which have been modified with pull-down-resistors to allow for reading their current state (pushed / not pushed) with the Arduino. Thus - controlled by software - they can be used as switches. To do so, the corresponding pin has to be watched. When the button is pushed, a switch-variable changes its value. A delay of a few hundred microseconds has to be implemented in order to prevent the variable to change its value too quickly (unless intended). Alternatively, switches that mechanically keep their state could be used. The buttons in the kit can of course still be used as simple push buttons.

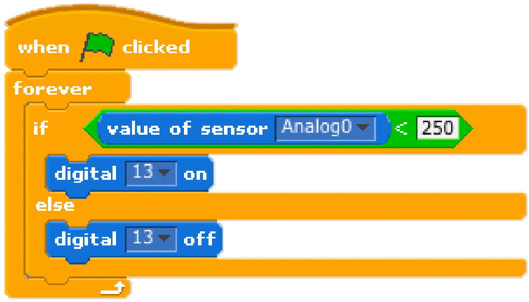
Potentiometer: Potentiometers are changeable resistors. They are perfect for manually and continuously controlling actuators such as the brightness of lights, the volume of speakers or the speed of a motor. Depending on the resistance a value between 0 and 1023 will be read on the matching pin.

Proximity sensor (IR): In this kit an infrared proximity detector is used. The infrared diode sends infrared light, which is only received by the sensor, when something reflects it. White objects are detected in a distance of up to 6 cm; black objects will only be detected when they are as close as 1 cm. If an object is detected, “low” will be read on the corresponding input pin. The proximity detector can be used as a very basic motion sensor and for contact-free switching.

An expansion of the construction kit could include the following additional components: hall-effect-sensors to detect magnetic fields, touch and pressure sensors, a light barrier construction, vibration sensors, ultrasonic sensors and many more.

The Actuators

For the actuators the same procedure is applied, as has been described for the sensors already. Standard and continuous rotation servos, LEDs and piezo sounders are part of the construction kit. Further components in a future version of the kit could include vibration motors, different types of displays (e.g. dot matrix, seven-segment, LCD) and many more.




```
int Sensor = A3;
int ledPin = 13;

void setup()
  {pinMode(ledPin, OUTPUT);}

void loop() {
  if (analogRead(Sensor) < 250)
    {digitalWrite (ledPin, HIGH);}
  else {digitalWrite (ledPin, LOW);}}
```

Fig. 2: S4A-program for controlling a lamp in comparison to its code-equivalent.

Activities and Examples

In accordance with the strategies for broadening participation, topics need be broad enough to encourage a variety of different projects. At the same time they should be specific enough to call for ideas and give students the possibility for meaningful discourse. Furthermore, topics should stimulate the students' imagination and even allow the construction of purely artistic projects that do not necessarily represent meaningful devices in reality. With *My Interactive Garden* all this is possible: such a garden can contain many familiar objects of everyday life, as well as futuristic objects that do not yet exist. This ensures that the students' perspective is not limited to devices they know from their environment. To give an impression of the various options, only a few possible projects are listed: lights that glow in different colors depending on the current weather conditions, automatically opening doors, automatic watering systems, alarm systems for house and garden, a balance bridge over the pond that opens for ducks when they come close, magical flowers that interact with people, a swing that starts to move when someone sits on it, solar lanterns, a sun screen that automatically opens when sunlight is detected, lamps that light when movement is detected, a rabbit hutch with an automated feeding system and many more.

In the following, two prototypical interactive objects are described; a simple and a more complex project, which demonstrate the idea of *My Interactive Garden*.

Magical Flower

A relatively simple and easy to realize project is the construction of a magical gleaming flower - a lamp, which is controlled by the intensity of ambient light (fig. 3). The value of a brightness sensor is processed and used to control one or more LEDs. When a measured value falls below a particular threshold value, the LEDs are turned on. The resistance of the sensor is the higher, the darker the environment. This means that in absolute darkness, the resistance is so high that no voltage (and therefore a value of 0) can be read on the corresponding analog input pin. If the ambient brightness is very high, the resistance is very low, and the maximum voltage is detected on the pin, which means that a value of 1023 will be read. A possible extension of the program is to control the LEDs with pulse width modulation (PWM) and thus to adjust the LEDs' brightness according to the ambient brightness. For this purpose output values need to be calculated in correspondence to the input signals. An even more complex task is to additionally change the color of the light in specified time intervals.

This example makes use of several computer science concepts. Loops and decisions are needed to turn the lights on and off. Moreover, students will learn about the representation of information and analog and digital data when using pulse width modulation to achieve differences in brightness. In classroom several analogical objects that require the same programming concepts can be created by different students, according to their interest and intended contribution to the interactive garden: e.g. automatic lanterns, house lights, disco lights and many more.

Fig. 3: Magical flower and bonfire

Bonfire

Depending on ambient light and temperature the bonfire "inflames" itself (fig. 3). For this purpose a light sensor and a temperature sensor are used. When the measured values exceed or fall below particular threshold values, three LEDs (red and yellow, diffused) are turned on with PWM. Brightness as well as the time of illumination are controlled by random values to create the effect of flickering. The bonfire is extinguished when the input signals exceed the specified threshold values or when it is blown out. For this purpose, a sound sensor is calibrated accordingly. To make sure the bonfire does not enlighten itself immediately after extinguishing it, a delay needs to be added to the algorithm. A possible extension of the project is to build a construction for roasting food over the fire. A servomotor can be used to rotate a rod to which the food is attached. In this example many programming concepts are needed: in addition to loops and decisions, variables, comparisons and arithmetic operations are relevant. Random numbers are used and messages exchanged to call subroutines in the program.

Discussion

My Interactive Garden picks up the ideas of Papert and transports them into the 21st century setting. Students can now be empowered to learn principles of computing by constructing meaningful interactive objects. Through feedback from computer science teachers, we know about the interest in applying the idea of creating interactive objects in the classroom, but also about trouble teachers and students have with the raw Arduino system. The construction kit provides them with pre-assembled sensors and actuators as well as an extension for the Arduino board containing connecters for input and output of data via sensors and actuators. The accompanying documentation delivers ideas for projects, which can be exhibited as part of the interactive garden. This way, developments in interactive computing systems are used authentically and form a motivating context for computing education, which in this way can be driven by challenges posed by students themselves.

At the moment only a prototypical version of *My Interactive Garden* exists. However, it is our intention, after a first test run in schools, to prepare the construction kit in a way that it can be provided to schools in larger quantities. Furthermore, the data sheets and construction plans for the kit are published allowing the recreation of every part.

The increasing pervasiveness of interactive objects will lead to a growing demand for educational material, which addresses these ubiquitous media both as tools, as well as subjects of computing education. Elaborating this thought, we are convinced that in the near future, children will not only take home from school a hand made vase made in pottery class but also interactive objects they themselves have created and programmed in computer science class.

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How to enhance the robotic experience with Scratch

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Abstract

The paper shows how deep a robotic experience can be using the Scratch environment. After some motivating reflections and remarks, the paper presents a sequence of demonstrative examples exploiting most of the Scratch commands able to promote such an experience. In the conclusions the possibility of using external hardware is also mentioned.

Keywords

Educational robotics, Scratch, Constructionism, IBSE

Introduction

When you read a paper or a report on the educational use of robotics, most times it is put in connection with the constructionist approach (Bers et. al., 2002; Goldman et. al., 2004, Chang et. al., 2010). This is not surprising: the original Papert's turtle was a drawing robot, basic educational robots like Bee-bot and Pro-bot (see http://www.tts-group.co.uk) are programmed with Logo-like primitives, and very often simple robot motion examples are based on commands very similar to the turtle's motion commands. Moreover most researchers agree on considering constructionism the correct and effective way both to introduce elementary robotics and to exploit all the educational potential that robotics can convey (Demo et. al., 2012).

In this sense Scratch (http://Scratch.mit.edu/) is not an exception: this successful legacy of LOGO tradition has various relations with robotics: it includes several commands to give sprites a stronger robotic apparatus, it is interfaced with external devices like Picoboard and LEGO WeDo useful for realizing physical robotic constructions, it has been extended to control a LEGO Mindstorms NXT or an Arduino system (http://www.arduino.cc/). Through a sequence of documented examples, this paper presents motivations for using Scratch to have an initial, deeper robotic experience before starting with a physical robot. Coming from our previous experience in Educational Robotics, this is a preliminary result of our research that, without denying the fundamental value of working with real robots in a real environment, can show how it is possible to have a rewarding experience in a known and widespread virtual environment, anticipating most of the competences successively developed with a real robot. A teacher could promote this approach designing a constructionist progression from Scratch as an authoring system, from Scratch as a virtual robotic environment, from Scratch with external devices for teaching control principles, towards the use of an autonomous real robot to face the uncertainties of the real world.

In the second section we provide some general motivations and discuss critical aspects that the literature and our personal experiences show. The third section is dedicated to the set of examples: as an auxiliary compact notation for this paper to present Scratch code, we will use a textual language which is defined and used in the official Scratch wiki and forums (http://wiki.Scratch.mit.edu/wiki/Block_Plugin/Syntax). Some final remarks conclude the paper.

Robotics at school: motivations and criticalities

Papert's great contribution was to build a educative "medium" specially adapted for children to make learning processes compliant with the psycho-genetic theories of Piaget (Piaget, 1972). The medium was a cinematic object: the LOGO turtle and a structured language of commands and functions to manage its behaviour, the LOGO language. Papert actually designed (without knowing it) one of the first educational robots (Papert, 1980).

The educational proposals based on Piaget's theories were initially radical: they were based on his proposition that "every time we teach a child something, we prevent him from finding it out by himself". Here we see the initial foundations of an active-autonomous learning through self-discovery that will be transformed, with Vygotsky's social contributions (Vygotsky, 1968), in active-driven learning through exploration/inquiry, i.e. what we identify today as social constructivist learning. Thus we see that the genesis of robotics at school, and of the methodological reasons for its introduction, derives from the conjunction between Piaget and Papert.

Enabling students to have "real" learning experiences (in the Piaget's sense) has been the main motivation of the development of LOGO in compulsory education. It is the methodology, rather than the content of learning, that matters, and the last educational goal was "learning to learn". The direct examination of physical objects by the child, according to Piaget, allows him to build logical schemas of concrete operations and to gain a equilibrium in the scope of his interaction with the environment.

But the exploration of the turtle exhibits substantial differences. You don't touch the LOGO turtle, you cannot directly interact with it, but only through its programming language. A "physical" exploration in the behaviour of the turtle is done through the linguistic exploration of its formal programming language. It is an indirect exploration, mediated by language. Though being a concrete exploration activity it is applied on a formal context, and in this case the discovering activity of the child allows him to build their own logic schemas of formal operations. The benefit of young people working with LOGO programming environment is to allow extending the same Piagetian methodology of learning through discovery to the construction of cognitive patterns of formal operations.

Clearly, in this first stage of "robotic learning" the greatest interest is in the functional and constructivist learning of the programming language as a vehicle for a constructivist learning of the formal spaces and their rules for the representation and communication of the world, for making students access the formal competences.

Common implementations of LOGO provide a working scenario (the environment) where we can control "actors". The language allows the interaction between actors, but does not realize the interaction between actors and environment. The environment is a purely decorative stage, a drawing of pixels, and an actor (turtle) can only detect the colour of the pixel on which is currently located. This leads to the design of microworlds usually without a stage, where the requested tasks and procedures are not dependent on the environment and deal with how to construct certain completely pre-determined geometric paths If you consider the usual LOGO procedure to draw a regular polygon, the task of the turtle is not conditioned by the environment. Consequently LOGO primitives commonly used in this kind of problems are commands and arithmetic functions for the movement of the turtle and the control statement "repeat". On the contrary, the conditional statement "if" is much more rare.

But an hypothetical-deductive thinking can be more complex, and it reaches a second level of abstraction when formulating and validating hypotheses about appropriate “behavioral conditions”. They are hypotheses about the variables expressing interactions with the environment: sensorized robots interact continuously with the environment.

Scratch offers advantages as an evolution of LOGO. While promoting, like LOGO, basic hypothetical thinking, its design moves around a more advanced interactive language and may allow, on the one hand, the simulation of “physical” environments and, on the other hand, the enrichment of its “sprites” with simulated sensors, i.e. it permits to work on the second level of the hypothetical-deductive thinking. This will be exemplified in the following sections.

Similarly as the LOGO turtle, a Scratch “virtual robot” has some advantages over physical robots, which are worth considering if you are more interested in a school constructivist work. These advantages regard the unavoidable uncertainty of a physical robot when translating into actions a given task. There are unavoidable differences between the values of the real structural parameters of a robot (influencing the actual behavior of the robot) and the theoretical parameters of the robot model (which are taken into account when solving the requested tasks). For example, common differences are in the actual wheel radius, in the actual width of the shaft between the driven wheels, etc.). There are also limitations on the engine power, the measurement accuracy of the sensors, there is uncertainty in the trajectory due to the inertia and friction, ... This causes a physical robot to implement a “conceptual” macro-task with imprecision. For example, it is hard to make the robot move straight and turn on the perimeter of a perfect hexagon, reaching a final state that is identical to its initial state. This is not due to an error in the formulation of the task (in the programme coding), but to an inaccuracy which is usually more significant in less sophisticated robots, such as in educational robots.

Scratch virtual robots, such as LOGO turtles, have not this problem because its accuracy is of the order of the density of pixels on the screen, which at present is high enough to consider it as an ideally perfect robot, at least in their 2D motions.

The immediate availability of the robot contributes greatly to maintain the motivation to advance in the constructivist process and to realize an effective learning. Conversely, the difficulty of having a personal physical robot (or one robot for a small group of students) sometimes makes hard, or even cancels it, a true exploratory learning. The requirement for direct interaction with the robot (even mediated by the programming language) is also here, in a “formal” constructivist learning, as important as it is in a “concrete” constructivist learning.

Robotics in Scratch

We present here a sequence of small demonstrative examples which show how deep the ‘robotic’ experience with Scratch could be. These examples were developed using the current 1.4 version. In some cases scripts were defined with the role of parameterized functions: thus a BYOB (http://byob.berkeley.edu/) implementation would be even more effective.

Simple motion

In (Alimisis et. al., 2009) the first examples proposed regard a simple straight-line motion in order to have a first deepening of the basic involved physical entities: space, time, linear and angular speeds. Scratch provides two ways to finely control motion: the *glide* basic command and using the *timer* support.

Starting from the simple example of a bus which has to stop in front of bus stops at fix distance (fig. 1, labels are independent, not moving sprites), let us set the *stopDis* variable to this distance and *busSpeed* to the requested bus speed, (space is measured in steps, the unit used by Scratch; time in seconds, thus speed is measured in steps/s), *numStops* the number of stops and *waitStop* the time the bus must stay at the stop before moving to the next one. The main loop to implement the travel is the following:

```
repeat (numStops)
     glide ((stopDis)/(busSpeed)) secs to x: ((x position)+(stopDis)) y: (y position)
     wait (waitStop) secs
end
```

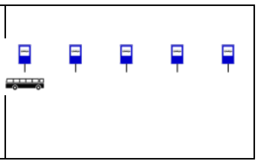


Figure 1. Simple bus motion

Unfortunately, there is no *glide* version where motion is specified in a relative form, i.e. using direction and distance, more reasonable for an autonomous robot which usually cannot refer to absolute Cartesian coordinates. Thus in our simulation we must calculate them.

When stops are in random positions, you can use the *point towards* to re-orient the moving sprite towards the next fixed stop, whereas the *distance* command evaluates the distance to be travelled for the next tract. These two commands can be seen as sensors of the robot sprite that return respectively the relative direction and distance of an object. Destinations are identified by sprite names, suitable chosen to facilitate their enumeration. The absolute coordinates of each target sprite are now calculated using the *x position of sprite* and *y position of sprite* commands (fig. 2).

```
repeat (numStops)
     change (i) by (1)
     set [stopName v] to (join [Stop] (i))
     point towards (stopName)
     glide ((distance to (stopName)) / (busSpeed)) secs to x: ([x position v]
of (stopName)) y: ([y position v] of (stopName))
     point in direction (90 v)
     wait (waitStop) secs
end
```

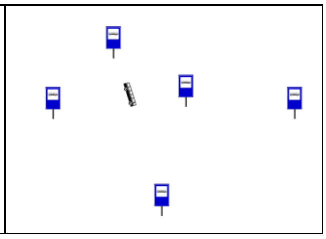


Figure 2. Random positions of stops

When bus stops are on a straight line but not at known distance, and we want the robot to recognize stop labels, we should provide it of a suitable sensor. This can be simulated using the *color <color1> is touching <color2> ?* boolean block. For example, if we add a small red filled rectangle in front of the bus 'costume' (shape) and we know that the label pedestals are black, the following code works (fig. 3, notice the color codes):

```
repeat (numStops)
     repeat until <color [#FF0000] is touching [#000000] ?>
          glide (((busStep)/(busSpeed)) -(0.06)) secs to x:
((x position) + (busStep)) y: (y position)
     end
     wait (waitStop) secs
     move (busStep) steps
end
```

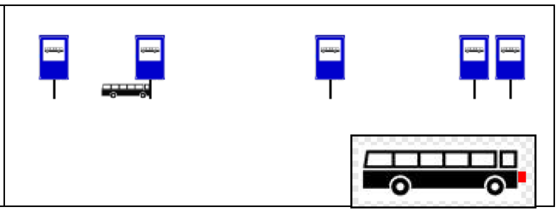


Figure 3. Sensorized bus

The bus moves through a small amount of *busSteps* steps and the speed is correspondingly tuned, including a 0.06 s of delay. The final move shifts the bus over the current label pedestal.

Obstacle avoidance

Obstacle avoidance is a very typical robotic challenge: we present here some examples of increasing complexity to show the wide spectrum of possibilities.

In the first example we assume to know the name of the 'obstacle' sprite. *touching <obstaclesprite> ?* returns true when the current sprite touches the other one in any point of their respective shape boundaries. With the code of fig. 4, if you put the robot sprite below the obstacle on its vertical, when the sprite reaches it, the sprite moves aside to avoid the obstacle.

```
repeat until <(y position) > (180)>
     change y by (3)
     repeat until < not <touching [ObstacleSprite v] ?>>
          change x by (10)
     end
end
```

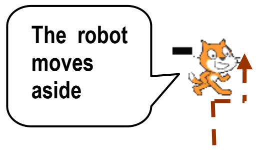
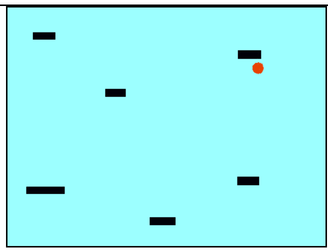


Figure 4. Simple obstacle avoidance

In the second example we have several obstacles in unknown positions but with known colors. In this case it is not even necessary that obstacles are sprites: they are directly drawn on the stage. *touching color <color> ?* reveals the obstacle proximity. We use also the *touching edge ?* block to make the sprite to remain within the stage boundaries. The red ball, i.e. the robot sprite, 'dances' bouncing on the encountered obstacles and on the edges (fig. 5).

```
forever  // main script
     move (3) steps
     if <touching color [#000000] ?>
          turn right (180) degrees
          repeat (10)
               move (2) steps
          end
          turn right (pick random (10) to (260)) degrees
     end
     if <touching [edge v] ?>
          turn right (pick random (70) to (160)) degrees
          move (4) steps
     end
end
```



```
forever // secondary script
   if < (distance to [mouse-pointer v]) < (10)>
         turn right (180) degrees
         move (30) steps
         turn right (150) degrees
     end
end
```

Figure 5. Bouncing ball

The interaction with the user is increased by the secondary script of the figure: if you move the mouse pointer near the moving sprite, it jumps a little. These two segments of code can (and must) be defined as independent, concurrent scripts, both activated with the *when green flag clicked* command. This adds a flavour of concurrency, an important aspect in robot controlling.

Next, we present a more structured solution, though the avoidance strategy is still elementary. The *touch* function returns 1 in *touch_yes* if the sprite touches one of the obstacles. To check this, we use *touching <obstaclename> ?* and again *numObst* obstacles have known, easily enumerable names (fig. 6). For conciseness we define a *glidedistt* function that executes a *glide* for *glidedistt_time* seconds and for a distance of *glidedistt_dist* steps in the current sprite direction.

```
when I receive [touch v]
set [i v] to (1)
set [touch_yes v] to (0)
repeat (numObst)
     if < touching (join [Obst] (i)) ?>
          set [touch_yes v] to (1)
          stop script
     end
     change [i v] by (1)
end
//-------------------------------------------------
when I receive [glidedistt v]
     glide (glidedistt_time) secs to x: ((x position) + ((glidedistt_dist) * ([sin v] of (direction)))) y: ((y position) + ((glidedistt_dist) * ([cos v] of (direction))))
```

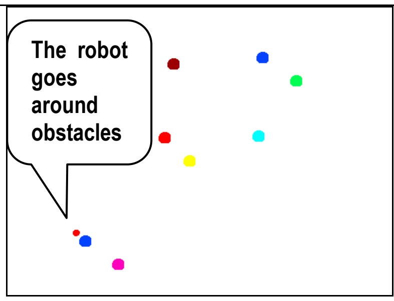


Figure 6. Touch and glidedistt functions

The avoidance algorithm could be straightforward: when during the motion in small steps the sprite touches an obstacle (*touch_yes* is true after calling *touch*), it tries to go around it and then it goes forward along the initial direction. In the following example we want that the 'going around dance' of the robot is performed when the minimum distance of the objects, which are in the angle of ± 15° with respect to the robot's axis, is lower than a given threshold. To evaluate such distances we simulate a distance sensor (ultrasonic sensor) through the the *dist* function in fig. 7.

```
when I receive [dist v]
set [i v] to (1)
set [dist_d v] to (3000)
repeat (numObst)
     set [dir_x v] to (<[x position v] of (join [Obst] (i))> - (x position))
     set [dir_y v] to (<[y position v] of (join [Obst] (i))> - (y position))
     broadcast [dir v] and wait
     if < ([abs v] of ((direction) - (dir_ang))) < (15) >
          if < (distance to (join [Obst] (i))) < (dist_d) >
             set [dist_d v] to (distance to (join [Obst] (i)))
          end
     end
     change [i v] by (1)
end
```

Figure 7. The dist function

The minimum distance is returned into the *dist_d* variable. The *dir* function (fig. 8) receives in *dir_x* and *dir_y* respectively the x and y components of a bi-dimensional vector and returns in *dir_ang* its direction, i.e. the angle of its polar representation. In *dist* it is called to calculate the direction of the conjunction of the sprite and the obstacle centres, relative to the sprite direction.

```
when I receive [dir v]
if < (dir_y) > (0) >
// to distinguish quadrants because sin/cos are not completely invertible
     set [dir_ang v] to <[asin v] of ((dir_x)/<[sqrt v] of ( ((dir_x)*(dir_x)) + ((dir_y)*(dir_y)) )> )>
else
     set [dir_ang v] to <[acos v] of ((dir_y)/<[sqrt v] of ( ((dir_x)*(dir_x)) + ((dir_y)*(dir_y)) )> )>
     if < (dir_x) < (0) >
     set [dir_ang v] to ((0) - (dir_ang))
end
```

```
// main script
repeat until << (x position) > (236) > or <(y position) > (176) >>
     set [glidedistt_time v] to (0.4)
     broadcast [dist v] and wait
     if < (dist_d) < (minDist) >
          // go around
     end
     set [glidedistt_time v] to [0.2]
     set [glidedistt_dist v] to [10]
     broadcast [glidedistt v] and wait
end
```

Figure 8. The dir function

The unspecified 'go around' section can be easily improved with respect to the previous example, using the *dist* function to avoid to go to the side of the first obstacle where another obstacle is very close (possibly declaring a failure if both sides have close obstacles).

We only mention a further example where we have provided a *scan* function which returns in two lists the distances and the directions, relative to the robot position and direction, of each one of the *numObst* obstacle sprites which are in the range of directions -90°÷+90° (i.e. obstacles that lie before the robot). This function can be thought as the equivalent of a “range scanner” sensor, providing distances and angles.

Other sensing

When you know the name of the target sprite, the two commands *point towards <sprite>* and *distance to <sprite>*, simulating the information usually given by a range scanner, give a sort of aligning sensor. Such tool can be used to realize simple forms of approaching and following other objects or moving robots.

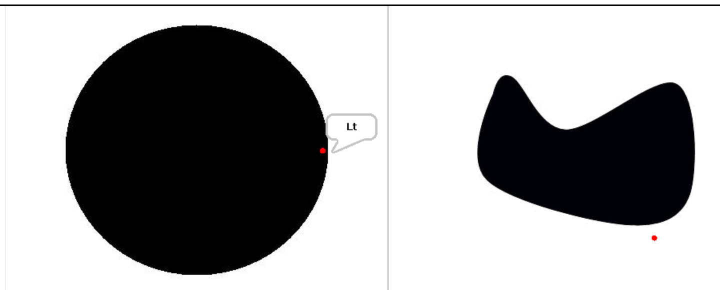
The PC microphone is interfaced with Scratch so that it acts as a sound sensor. The level of the perceived sound can condition a script through the *loudness* sensor returning a value in the range 0÷100. Another possibility we suggest for simulating a robot equipped with a sound sensor, or a phonometer, is to imagine a source, represented by one sprite, emitting a sound with a given power and the robot that measures a certain acoustic pressure level which depends on the source power and the distance. For a spherical propagating sound, acoustics defines a pressure level at distance *r*, measured with the logarithmic scale of dB, as follows:

$Lp = Lw - 20 \cdot log_{10}\, r - 11\ (dB)$ $\qquad$ $Lw = 10 \cdot log_{10}\,(W/W_0)$

where Lw is the acoustic (constant) power level, that depends from the source, W is the source sound power, W_0 is the power of the minimum audible source, conventionally set at 10^{-12} W(att). In your program you can assume a certain value for Lw and calculate Lp calculate Lp with the formula above.

Line following is one of the basic robot application using a light sensor: pointing it towards the floor, it makes the robot to distinguish a light area from a dark area and therefore, suitably modifying the direction of the robot, you can maintain it along the border of a black shape on a white plane. We simulate the comparison of the level measured by the light sensor with a certain threshold with the on-off response of the *touching color <color> ?* boolean block. Consider this simple solution (fig. 9).

```
goto x: (-170) y: (0)
point in direction (0 v)
forever
     move (1) steps
     if < touching color [#000000] ? >
          turn left (2) degrees
          say [Lt]
     else
          turn right (2) degrees
          say [Rt]
     end
end
```



a) Around a circle $\qquad$ b) Complex shape

Figure 9. Line follower

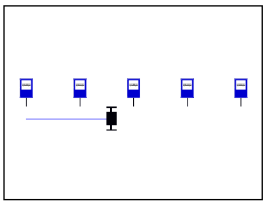
The robot, represented by a very small red circle, moves clockwise around the black circle near its boundary. Unfortunately, even not surprisingly, this simple solution suffers of a certain instability which makes sometimes the robot fluctuating more or less far from shape boundary. This is more evident on a more complex shape like the on in fig 4b.

Simulation of a motorized robot

Now we attempt to more precisely simulate a physical robot with one or two motors, two wheels for imparting the motion energy and assuming that the robot can turn like a robot turtle.

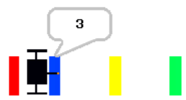
In the first example we have a one-motor robot running on a straight line. We have realized a *motor* command, similar to that realized in NXT-G for the LEGO Mindstorms NXT robot. It receives 4 parameters: *motor_power*, regulating the motor angular speed, *motor_dir* specifying the direction (forward or backward), *motor_dur* specifying a generic duration which depends on its type *motor_durtype* as follows: when *rot*, *motor_dur* is the number (with fraction) of full rotations; when *sec*, it is a time measured in seconds; when *deg*, it is the number (with fraction) of degrees to be sweeped. The robot configuration parameters are the maximum angular speed (*maxangspeed*) and the wheel radius (*radius*). The *motor* implementation first calculates in *ang* the requested motion angle and in *angspeed* the angular speed, proportional to *motor_power* so that speed is *maxangspeed* when *motor_power* is 100. The motion is performed in a certain number of steps long *astep* units each. So the total distance (*dist*) and the corresponding time quantum (*tstep*) are evaluated. To permit to stop the movement in any moment, a *stop* flag is used, set by the concurrent *stop* command. We also add an *lmotor* command which receives a linear distance parameter (*lmotor_dist*) instead of the *motor_durtype/motor_dur* couple. Setting the *motor* parameters you can move forward or backward the robot in a finely controlled way, for example with the distance stops bus problem (fig. 1). You can also add the equivalent of a color sensor to the robot, putting a small colored square on the tip of a protuberance that comes out from the robot body (fig. 10).

```
when I receive [motor v]
set [stop v] to (0)
set [angspeed v] to  (((maxangspeed)*(motor_power))/(100))
if < (motor_durtype) = [rot] >
     set [ang v] to ((motor_dur)*(360))
else
     if < (motor_durtype) = [sec] >
          set [ang v] to ((angspeed)*(motor_dur))
     else
          set [ang v] to (motor_dur)  // degrees
     end
end
set [dist v] to ((((ang)*(3.1416))*(radius))/(180))
set [astep v] to (2)  // linear step
set [tstep v] to (((ang)*(astep))/((angspeed)*(dist)))
set [time v] to ((tstep)-(0.1))  // final instant
reset timer
repeat ((dist)/(astep))
     move ((astep)*(motor_dir)) steps
     wait until < (timer) > (time)>
     if < (stop)=(1) >
          stop script
     end
     change [time v] by (tstep)
end
```



```
when I receive [lmotor v]
set [motor_durtype v] to [deg]
set [motor_dur v] to
(((lmotor_dist)*(180))/((3.1416)*(radius)))
broadcast [motor v] and wait


when I receive [color v]
if <color [#FF9400] is touching [#FFFFFF] ?>
     set [color_color v] to (0) // white
else
     if <color [#FF9400] is touching
[#000000] ?>
          set [color_color v] to (1) // black
     else
          if <color [#FF9400] is touching
[#FF0000] ?>
               set [color_color v] to (2)  //
red
          else
          . . .
end
```



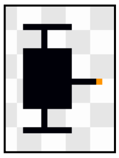


Figure 10. The motor command and a color sensor

The *color* function returns in *color_color* a color code. The relative complexity of this coder is due to the fact that in the current version of Scratch we cannot refer directly to color codes.

The last example is the most complex one because it tries to simulate a steering robot with 2 drive wheels with separate motors. The *move* command receives parameters similar to *motor*, plus *move_steer* representing the steering level, (0 = no steering, 10 = pivoting). With *move_steer*=0 the robot go straight and this part of the implementation is equal to the *motor* command. When *move_steer*>0, we assume that $\omega_l > \omega_r$ (ω_l and ω_r angular speed respectively of the left and right wheel) and that ω is set on the basis of *move_power*, whereas ω_r depends on the steering value. Say d the distance between the two wheels; the radius R drawn by the internal wheel is given by (for a detailed description of the theory, see Alimisis et. al., 2009)

$R = d \cdot \omega_r / (\omega_l - \omega_r) = d \cdot (\omega_r/\omega_l) / (1 - \omega_r/\omega_l)$

For simplicity, we assume a reasonable linear relation between the ω_r/ω_l ratio and the steering s.

$\omega_r/\omega_l = 1 - 1/5 \cdot s$ $\qquad$ $R = d \cdot (1 - 1/5 \cdot s) / (1-(1 - 1/5 \cdot s)) = d \cdot (5 - s) / s$

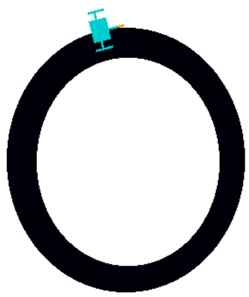
Say $a_l = \alpha_{wl} \cdot r$ the length of the arc in radians of radius $R+d$ drawn by the external wheel, and r the wheel radius. In the motion the steering radius draws an angle Θ and for its measure it holds:

$\Theta = a_l / (R+d) = \alpha_{wl} \cdot r \; / (R+d) = \alpha_{wl} \cdot r \; / ((d \cdot (5 - s) / \cdot s) + d) = \alpha_{wl} \cdot r \cdot s \; / (d \cdot 5)$

Θ is the angle drawn also by the two other radius, R for the internal wheel and $R+d/2$ for the robot centre. Thus this latter must draw an arc a_c of length:

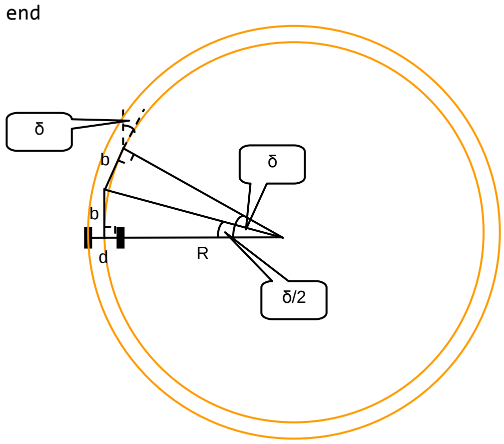
$a_c = \Theta \cdot (R+d/2) = \Theta \cdot d \cdot (10-s) / (2 \cdot s) = \alpha_{wl} \cdot r \cdot (10-s) / 10 \qquad (\alpha_{wl} \cdot in\ radians)$

```
// stop, angspeed and ang as in motor command
set [dir v] to (1)
if < (move_steer) < (0) >
     set [dir v] to (-1)
// dir gives the turning side +1=right -1=left
     set [move_steer v] to ((0) - (move_steer))
end
if < (move_steer) = (0) > // this is equal to motor
reset timer
else
     set [theta v] to ((( (ang)*(radius) )*(move_steer)) / ((wdist)*(5)))
     set [astep v] to (( ((([tan v] of (1))*(wdist))*((10)-(move_steer)))*(move_dir)) / ((move_steer)*(2)))
     set [tstep v] to ( ((ang)*(2)) / ((angspeed)*(theta)) )
     set [time v] to ((tstep)-(0.1))
     reset timer
     repeat ((theta)/(2))
          move (astep) steps
          turn right ((2)*(dir)) degrees
          move (astep) steps
          wait until < (timer) > (time) >
          if < (stop) = (1) >
               stop script
          end
          change [time v] by (tstep)
     end
     change [time v] by ((0) - (tstep))
end
```



b) line follower

```
// line follower application
set [move_dir v] to (1)
set [move_durtype v] to (sec)
set [move_dur v] to (6000)
set [move_power v] to (100)
forever
     boadcast [stop v] and wait
     if <color [#FF9400] is touching [#FFFFFF] ?>
          set [move_steer v] to (-2)
          broadcast [move v]
     else
          set [move_steer v] to (2)
          broadcast [move v]
     end
end
```



a) the path

Figure 11. The steering robot

We execute this motion of the sprite centre on a arc of circle, which produces a total rotation of Θ of the sprite axis, repeating Θ/δ small angular steps of δ units. We approximates this micro-motion with a sequence of move-turn-move commands so that, after one small step, the position and direction of the robot are the expected ones with a real arc of δ units. It results:

$b = R_c \cdot tg\ (\delta/2) = (R+d/2) \cdot tg\ (\delta/2) = d \cdot (10\text{-}s) \cdot tg\ (\delta/2)\ /\ (2 \cdot s)$

So the sprite, executing a *move(b)*, *turn(δ)*, *move(b)*, reaches the correct position and orientation after one step. Experimentally we chose δ=2 as its minimum feasible value. Fig. 11 shows an application, a line follower with the robot equipped with the equivalent of a light sensor. The stop command provides a way to resetting a previous *move* command (*broadcast* without *wait*).

Conclusions

As shown in this paper, Scratch includes several features which can be attributed to usual robotic behaviours. Carefully exploiting these features makes it possible for a student to have a significant experience of 'virtual' robotics in a 'virtual' environment which is a probably already known and not complex authoring system. Therefore, before working with a real robot, most important aspects of robotics having an educative value can be easily transferred.

Interfacing an authoring system like Scratch with external hardware can further improve the user robotic experience and make her closer to the positive learning potential that a real, full-featured robot exhibits. Scratchboard, LEGO WeDo but especially the low-cost Arduino system are currently interfaced with Scratch (for example see *Scratch for Arduino* (S4A), http://seaside.citilab.eu/scratch/arduino). The smooth learning progression from basic robotics to experiences with external hardware is more effective when we start with the 'robotics' features of Scratch like the ones we exploited in our experimentation.

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The Symbiosis of Design and Inquiry-Based Learning in Creating Robotic Models of Biological Systems

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Abstract

This paper considers an approach, in which design and inquiry-based learning are combined to meet the challenge of inquiry into a biological phenomenon and development of its technological representation in the form of a robotic model. Our multi-case study involved middle school students and prospective teachers. The study considered learning processes, in which the students used the PicoCricket robot construction kit to create a variety of bio-inspired robotic models. We propose the outline for such learning processes. Based on analysis of learning activities along with the studied cases, we extracted characteristics of the robotic modelling environment, formulated principles of the integrative learning, and evaluated its educational outcomes. The findings indicate the potential of robotic modelling as a way to symbiotically combine engineering design and scientific inquiry into an integrative learning activity.

Keywords

Science-technology education, Design, Inquiry, Robotics, Biological system, Modelling, PicoCricket.

Introduction

Recent literature emphasizes potential benefits of the "accommodation between science and technology education in the curriculum" (Lewis, 2006; Fensham, 2009). Lewis proposes to study engineering design and scientific inquiry at school in ways that utilize their complimentarity and conceptual proximity. One way is to employ design as a vehicle for teaching scientific content, and the other is to harness science as the driving force for prompting design. Lewis suggests design as a bridge between science and technology education towards achieving scientific and technological literacy. This goal, so he argues, calls for new interdisciplinary pedagogies "that are integrative in approach, showing fluidity between engineering and science". In this regard, Fensham (2009) points to the need of studying technology as the real world context of science and as the way for applying science to serve society.

Resnick, Berg and Eisenberg (2000) emphasize yet another argument in favour of keeping the technological content in the curriculum: failing to do so may lead to a situation in which technological systems utilized in science education are grasped as "opaque" black boxes, without understanding the principles of their operation. To avoid this circumstance, the students should be nurtured to “look inside” the technological artefacts in the world around them and develop their own tools for exploring phenomena in their immediate environment.

Researches considered possible ways to implement learning by design and inquiry in the middle school science and technology curriculum. Kolodner (2003, 2009) analyzes learning-by-design processes, in which the learners, triggered by an explicit design challenge, “mess about,” generate ideas, identify what they need to inquire, collect data, and gradually build artefacts. Kolodner presented a learning model that combines design and inquiry activities organized in two connected cycles: the "Design\Redesign" cycle answers the "need to do" while the "Investigate & Explore" cycle answers the "need to know". The proposed model is grounded on the principles of constructionism (Papert, 1991) arguing in favour of involving the learner in the creation of artefacts serving as “objects to think with”. In the cases presented by Kolodner (2003), design of technological artefacts was motivated by the need to understand scientific concepts.

When acting towards integrative teaching of natural science and technology through binding design and inquiry, or in any other way, we need to take into account the different nature of the two domains. Science focuses on natural phenomena, while technology deals with man-made creation (Ropohl, 1997). Standards for technological literacy define the relationship between science and technology from the perspective of symbiotic interdependence: "Science is dependent upon technology to develop, test, experiment, verify, and apply many of its natural laws, theories, and principles. Likewise, technology is dependent upon science for its understanding of how the natural world is structured and how it functions" (ITEA, 2000). Another manifestation of the relationship between science and technology is based upon the aspiration in both domains to borrow ideas of one another (Verner and Cuperman, 2010). Robot design, as well, is greatly influenced by the attempt to imitate appearance, functionality and behaviours of nature-made creatures and, in particular, the human being locomotion and intelligence. In the opposite direction, science is trying to understand and explain natural phenomena by exploring existing, or specially developed technological systems. The above mentioned manifestations are explicitly based on analogies between natural and technological systems. Researchers note that exploring such analogies not only facilitates the development of science and technology, but can also make a strong contribution to education (Gilbert et al., 2000).

The principles of integrative learning of science and technology are discussed by Resnick, Berg and Eisenberg (2000). They proposed a constructionist approach that encourages students to design their own instruments and use them for experimental inquiries. The authors point out that this approach can "deepen students’ understanding of the scientific concepts involved in the activities." Based on the constructionist approach, this paper proposes to facilitate learning of science and technology by a practice in which the learner investigates and explores a biological system along with the design and construction of its robotic model.

Learning with Robotic Models

Elmer and Davies (2000) point out that the purpose of modelling activities in design and technology education is more than acquisition of technical capabilities; it includes development of thinking skills. The same view underlies the concept of digital manipulatives introduced by Resnick et al., (1998). Accordingly, manipulative materials with embedded capabilities for sensing, computing and communicating open opportunities for creative construction of technological systems and foster systems thinking. A key feature of a digital manipulative is that it can be programmed to demonstrate a reactive behaviour. In educational practice, the inspiration to develop a digital manipulative and program its behaviour usually comes from the desire to reflect on phenomena and imitate behaviours existing in the world around us. Thus, the digital manipulative serves as the object-to-think-with in learning practices of its construction, programming, and exploration. We consider such a digital manipulative to be in essence a robotic model which is both a technological system and a representation of a phenomenon. Learning with a robotic model can occur in two domains: one in which the model is designed, built, operated and evaluated as a technological system, and the other, in which the model is understood and assessed as a representation of a phenomenon.

The concept of robotic model can be better understood when contrasting it with the concept of model commonly used in science education. It seems reasonable to make this comparison in terms of the following categories used by Ropohl (1997) for the comparative analysis of knowledge types in science and technology:

- Models in science education are *objects* usually presented in a generalized symbolic form. Physical models, and especially dynamic ones, are rare and mainly used as visual aids (Lipson, 2007). A robotic model, on the other hand, is a dynamic physical object which facilitates learning through hands-on activities of its construction and operation.
- The *objective* of modelling in science education is to assist understanding of phenomena and share knowledge (Seel & Blumschein, 2009). Practice with a robotic model serves an additional purpose of fostering systems thinking through devising an artefact.
- Regarding the *methodology*, a model in science education is treated as an ideal representation, while practical considerations are overlooked. Robotics education, in contrast, deals with models that function in the real world.
- Regarding the *characteristics of results*, the outcome of modelling in science education is a mental model that is formed in learner's mind. Modelling in robotics education prompts several outcomes: a mental model of a scientific concept, a mental model of a technological system, and a robotic model. Here the robotic model is a technological expression of scientific concepts acquired by the learner (Papert, 1991).
- *Criterion of quality* of a model in science education is its suitability to promote the acquisition of valid conceptions while avoiding misconceptions. A robotic model answers yet an additional criterion of proper functioning.

To summarize the comparison, a robotic model can feature as a science model with the added value of being a real technological system. In the context of this study, the learner, being engaged in devising a robotic model that represents a biological system, develops interconnected mental models of the biological and technological systems.

The proposed approach to learning with robotic models goes beyond robotics courses that concentrate on building simple mobile robots and programming basic reactive behaviours. We follow the new strategies for introducing students to robotics, as recommended by Rusk et al. (2008): focusing on themes, not just challenges; combining art and engineering; encouraging storytelling; organizing exhibitions, rather than competitions.

Indeed, creation of a robotic model of a phenomenon is a theme which combines engineering thinking with personal artistic expression. The developed robotic model is used not for competition, but serves as a tangible exhibit which assists storytelling concepts of science and technology.

Rusk et al. (2008) noted that there are different robot construction kits, each of which supports some type of activities and learning styles better than others. In this regard, the authors recommended the PicoCricket kit as suitable "to combine art and technology, enabling young people to create artistic creations involving not only motion, but also light, sound, and music".

Modelling Biological Systems

Based on the discussed view of learning with robotic models, we developed an instructional unit

"Control in Technological and Biological Systems" and delivered it to prospective teachers of science and technology, high school and middle school students. Dozens of instructional models were developed by our students in the framework of teacher training and outreach courses. The models featured topics such as: plant tropism, animal behaviour, control in biological systems in general and homeostasis in particular. All the models were built using the PicoCricket robot construction kit. The kit consists of a programmable microcontroller that can operate different actuators and manage input from various sensors. The microcontroller provides bi-directional infrared communication with a host computer or other PicoCrickets. In addition, data management capabilities are offered, with an opportunity to sample data from the sensors, implement reactive behaviours, and upload the data to a computer for graphical representation. These capabilities can further promote the use of the kit as a tool for inquiry based learning. The PicoCricket "specialties", such as pre-programmed animal voices, colorful lights, and craft materials, are useful for building robotic models of animals and other biological systems.

A Venus Flytrap Model

The nature phenomenon studied and modelled in this project was the ability of the Venus flytrap plant to detect and trap a prey.

Inquiry into the phenomenon. Closure of the Venus flytrap is one of the fastest movements in the plant kingdom. The trap consists of two lobes, which close together forming an enclosed pocket. The center of each lobe contains three mechanosensitive trigger hairs. When a prey crawls into the trap it bumps into the small trigger hairs. Two touches of a trigger hair are needed to activate the trap which snaps in a fraction of second. The closing process essentially involves a change of the leaf's geometry. The upper leaf is convex in the open position and concave in its closed position. The driving force of the closing process is most likely the elastic curvature energy stored and locked in the leaves. (Volkov et al., 2007; Pavlovic et al., 2010)

The model. The Venus flytrap model, shown in Figure 1 includes two touch sensors, and a dc motor driving a crank that can open or close a trap shaped mechanical structure. The PicoCricket executes the program written in PicoBlocks to implement the model behaviour. When creating the model, the students used technological means for developing a sensing mechanism to imitate the mechanosensitive trigger "hairs", and a trap mechanism, to imitate the Venus flytrap "lobes". The PicoBlocks program implements the following behaviour: when two successive touches on any of the sensors or a simultaneous touch on both sensors are indicated, the motor is actuated and the trap mechanism closes.

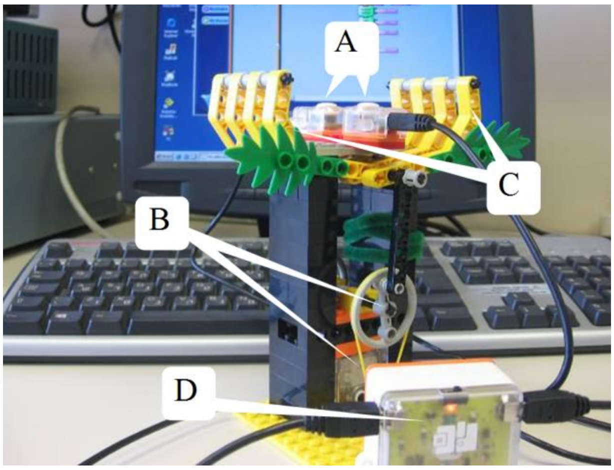

Figure. 1. The flytrap model: A. Sensors; B. Motor & crank; C. Trap mechanism; D. PicoCricket.

Educational Study Framework

The goal of this study was to develop and evaluate an approach to integrative learning of robotic and biological systems through modelling activities. We conducted a series of case studies in which the instructional unit "Control in Technological and Biological Systems" was delivered to prospective teachers of science and technology (N=22), high school students (N=14), and middle school students (N=73). The multi-case study framework enabled us to examine the proposed integrative learning approach across differences between the groups in their backgrounds and learning objectives.

The instructional unit was crystallized along with the case studies. As a first step, two case studies were conducted in the framework of our course for prospective teachers. Data were collected by means of pre-course and post-course questionnaires, semi-structured interviews with the students, and by artefact analysis. The insights we got from those two preliminary case studies helped us to refine the instructional unit for further case studies of teaching school students.

While striving to follow up implementation of the educational strategies, proposed by Rusk et al. (2008), we applied the inductive reasoning method (Lodico et al., 2010), trying to systematically examine our course in different learning situations. We observed typical learning behaviours, as well as features of integrative learning. The data were collected, triangulated and analyzed by mixed methods, following the integrated methodology (Plowright, 2011, pp. 6-22). Learning behaviours and their dynamics were observed along with the development of robotic models, while data were collected through observations, videotaping, interviews and questionnaires. Meaningful information was also obtained through artefact analysis and evaluation of the models developed by the students. In this evaluation we referred to model's complexity and to the characteristics of analogical resemblance between the model and its source, such as appearance, functionality and structure (Verner and Cuperman, 2010).

Findings

Attitudes towards Learning with Models

Prospective Teachers

A post-course questionnaire was offered to part of the students (N=12). It asked about attitudes towards learning with models and requested recommendations about ways to incorporate physical computerized models into learning activities. The questionnaire indicated that all the students were strongly interested to build physical computerized models and use them as teaching aids. More than 83% of the students recommended in-class demonstrations and experimentation with ready-made models, while all the students strongly recommended engaging learners in making models as part of inquiry activities. These results are in line with students' reflections expressed in the post-course interviews. The students recognized the advantages of learning with models, and especially, the value of models as means for visualizing dynamic processes:

"There are things you can only visualize using physical objects, which you can touch, change and play with." (A student majoring in technology education)

The students stated that the educational benefits of practice with models justified the effort of model making, and that this effort was less than expected:

"The effort was justified. When you create, build something, this enhances the learning process." (A student majoring in technology education)

School Students

Pre-course and post-course questionnaires on attitudes towards learning with models were conducted in the course delivered to high school students (N=14). Before the course, all the students expressed interest or strong interest to practice learning with physical computerized models. They all were more interested to focus practical activities of the course on building instructional models rather than on using pre-build models. Over 78% of the students assumed that practice with models will be helpful. After the course, all the students stated that practice with robotic models, and especially designing and building robots, really helped to learn the science and technology concepts of the course.

Features of Integrative Learning

Based on the observation of students' activities of model creation and analysis, in the first case studies, we found that the activities can be divided into five stages:

Stage 1. Acquiring technological knowledge. The learners were provided with knowledge essential for using the construction kit and building simple robotic systems. In particular, the students learned about sensors, control, simple mechanisms, motors, actuators, and intuitive brick programming. When introducing concepts related to technological systems we deepened into their scientific principles and explained them using their connection to similar concepts related to biological systems.

Stage 2. Selecting a biological process. The students were assigned to inquire a specific biological control mechanism within a selected topic. They selected the modelling tasks, while taking into account technological opportunities provided by the construction kit. In one case study, for example, the students selected from various phenomena of plant tropism. They examined ways to model this plant behaviour using the sensors available in the kit.

Stage 3. Inquiry into the biological system. The learners were engaged in a self-regulated inquiry, in which they studied the characteristics of the nature phenomenon relevant for creating the robotic model. Special attention was paid to the biological mechanisms to be imitated by the robotic model.

Stage 4. Building the model. The learners designed and built the robotic models through rapid prototyping rounds, in which characteristics of the model prototype were examined and improved to match those of the biological system.

Stage 5. Assessing differences and similarities. Once the model development was completed, the learners were assigned to individually answer the post-course questionnaire and systematically analyze the analogy between the model and the biological system.

One can see that the constructionist approach underlies the integrative learning process, so that at each stage learning occurs while a sharable artefact (physical or conceptual) is created.

When examining the integrative learning process our focus was on students' perceptions of the environment and indications of learning that repeated throughout the case studies. The features of integrative learning that emerge from this examination are as follows:

- The interplay between construction and inquiry in the creation of a robotic model is a motivating factor for integrative learning of science and technology.

  Observations indicated that the interest to build a robotic model triggered students' curiosity to the biological phenomenon. We also noticed that the aspiration to implement discovered knowledge into an authentic model drove effort to adequate construction. Those findings emerged also from reflections of both the prospective teachers and the school students participated in the study.

  "The method arouses motivation to learn. Working with the robotic kit was attractive and interesting. The combination with scientific content was good and helped us to learn, so the concepts were better understood and remembered." (A student majoring in mathematics education)

- Constructing robotic models through rapid prototyping is an effective strategy for supporting integrative learning.

  While the construction of a robotic model using the PicoCricket kit was rapid (a few hours) it drove the student toward an experiential learning cycle of technological prototyping along with agile scientific inquiry.

  "When I built the model I went back and check the scientific concepts behind the model." (A student majoring in technology education)

- Students' involvement in the analysis of similarities and differences between the model and the biological system can facilitate integrative learning of robotics and biology. Limitations of modelling tools can reinforce the challenges of the inquiry and design-based learning.

  This effect was observed in several cases. An example is the process of perfecting the mechanism for modelling tropistic movements in plants, observed in the Venus flytrap project. In this model, described in Section 3, the "trap" movement is generated by powering an electric motor that changes the orientation of two "lobes" via a crank mechanism. Further inquiry of the trap closure in the plant revealed that its mechanism is different and utilizes stored elastic energy to change leaf’s geometry. This finding motivated the development of a more realistic mechanical solution in the succeeding project. The developed solution, that imitates the plant hydrostatic pressure movement mechanism, utilizes pneumatic pressure to simultaneously unfold two "leafs" and move them apart.

To further facilitate the integrative learning, we asked the students to evaluate the similarities and differences between the model they built and its source. Analysis of those written evaluations indicated that the students, when comparing the biological systems and robotic models, examined the features of appearance and functionality.

Characteristics of the Learning Environment

We found that the following features of the environment are essential for sustaining the learning process:

- The learning environment should provide the integral infrastructure for both conducting scientific inquiry and building robotic models. From our experience, in addition to facilities for inquiry (web access) and modelling tools (robot kit, craft materials and instruments for modular construction and programming), a gallery of previously developed models serves as a worthwhile constituent of the environment.
- A team of two or three learners was found preferable for providing self-expression and opportunities of contribution, while still allowing the benefits of team diversity and collaboration. As observed, the students formed the project teams by themselves. Each student typically took leading in one of the three project areas: inquiry, building and programming.
- A framework, in which teams share the same open workspace, facilitated active interactions within the teams, between the teams and between the students and the teacher. In our course, team workplaces were organized to provide space for individual and team activities, while collectively using facilities for inquiry and modelling. During the workshops the teams were free to communicate and discuss their ideas and insights. The teacher's guidance was directed to facilitate both inquiry and model building activities. The teacher stimulated students' inquiry by asking questions that invoked further investigation and prompted the need for validation of results.

Learning Outcomes

Course assessment throughout the case studies provided notable indications of learning achievements in both scientific and technological competences. The assessment was based on oral and written descriptions of the inquired phenomena and their models, provided by the students in open discussions, presentations, project reports and knowledge questioners. Technological competences were also assessed by the analysis of robotic models and construction activities. Assessment results indicate that each student in the course advanced in knowledge and skills related to technological literacy, especially in relation to design, the nature of technology, and the abilities for a technological world. When creating the models, the students acquired and practically demonstrated skills of robot construction, programming and operation. The progress in learning technological concepts was indicated by the literate explanations given by the students when presenting their models. The gain of knowledge in biology was assessed through the analysis of students' oral and written explanations. Literate use of biological concepts was examined in collaboration with biology teachers.

The teachers helped students to validate information that they collected through inquiry. In some cases this was followed by an intriguing discussion. For example, one of the students built a robotic model of the sunflower heliotropism process, described in our previous paper (Verner and Cuperman, 2010). When inquiring sunflower's movement towards the sun (heliotropism), the student found in literature that the flower-head movement is caused by differential translocation of auxin (a plant growth hormone). The hormone causes greater cell elongation in the shaded side of the stem, bending the stem and ending in the flower-head facing the sunny side (Sherry & Galen, 1998). When he presented this information to the biology teacher, she first disagreed, arguing that the mechanism behind the phenomenon is probably related to changes in hydrostatic pressure. Such changes in the pulvinus (a joint-like thickening at the base of the stalk of a leaf) cause its expansion and lead to leaf movement. After a deeper examination the teacher acknowledged that the explanation given by the student was correct and that her version is relevant to leaf movement.

Discussion and Conclusion

Our research is motivated by the need for new ways to bridge science and technology education in middle schools. It proposes a learning environment, in which the study of a scientific phenomenon prompts and inspires practical activities, which in turn drive further learning of scientific concepts. Specifically, the students perform inquiry into biological systems to acquire knowledge needed for creating robotic models. In this setting, the robotic model becomes a "nucleus", which organizes and triggers the learning of technology and science subjects around the modelling process. All stages of this modelling process, i.e. the model ideation, materialization and exploration, have their specific educational roles.

The students are becoming involved in model ideation from the first experiments with the robot kit, when they explore analogies between its components and biological organs. From these analogies the students acquire a new perspective on biological systems and gain motivation to develop robotic models. The ideation continues, when the student selects a biological system and performs a self-regulated inquiry into its control mechanism. At this stage the student applies knowledge on control of technological systems to the study of biological systems, and ideates the concept of the model. At the materialization stage the student creates the model through iterations of rapid prototyping. The aspiration to improve the prototype directs the learning towards in-depth understanding of the biological system and development of effective technological solutions. At the model exploration stage, the analysis of similarities and differences between the model and the biological system guides the student to evaluate the model and the learning outcomes. From the aforesaid, the student can derive additional benefits from the design and construction of a robotic model beyond those that can be obtained from the analysis of a prebuilt model. This conclusion is in line with findings of other researches (Milard, 2002).

Our study indicated that the proposed course of action fostered growth in learners' scientific and technological literacy, positive attitudes towards teaching and learning with models, and motivation for building robotic models. Because of the limited assortment of components and materials in the kit, the robotic model can provide only partial analogical resemblance to the biological system. This opens a room for examination of similarities and differences between the source and the target, a systematic activity that facilitates integration and better understanding of both subjects. Findings of our research indicated that the examination of both similarities and differences was a meaningful learning experience for the students.

While guiding inquiries into biological systems towards creating the model, we acted to avoid inaccuracies in acquisition of biological concepts that might happen while self-regulating learning. We encouraged the students to carefully analyze specific features of the biological systems and consult with biology teachers to validate findings of this analysis.

In conclusion, we acknowledge the potential of modelling as a thread, tying together engineering design and scientific inquiry into an integrative learning activity. We continue the study of the proposed approach towards deeper understanding of cognitive mechanisms and wider implementation of learning with analogies.

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Toward A Data Expression Toolkit: Identifying the Elements of Dynamic Representational Competence in Young Learners

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Abstract

*We report on part of an on-going project to **identify and support** **dynamic representational competence** **as a constructionist competency for the 21st Century**. Specifically, we seek to identify patterns in how young learners construct visual representations of situations where quantities change over time. We collected interview and written data from 7th graders as they created representations of situations that featured simple, complex, and statistical patterns of quantitative change. For these students, we found that representing change involved 1) creating a* static setting *to provide context, 2) creating* dynamic objects *to indicate what is changing, 3) shifting objects'* location or form *to indicate change over time, and 4) defining* rules *for how objects should respond to future changes. This has implications for the teaching and learning of data/quantitative literacy, and for the design of constructionist toolkits for representing data.*

Keywords

Data science, metarepresentational competence, dynamic systems, representation, inscription, visualization, computational toolkits

Motivation and Vision

Advances in computational technologies have increased our ability to collect, store, and manipulate information about the world. As a result, educators have started to explore how we can help students to develop new literacies related to data, statistics, and quantitative reasoning, and to better understand the role of data collection, processing, and manipulation in scientific practice. Often, this takes the form of engaging students in collecting and analysing their own data using scientific probes, publicly available data sets, and statistical analysis and visualization tools. However, most such tools rely on established and emerging conventional representations of data: few build upon the competencies young learners *already* possess for making sense of and expressing their understanding of the world with data. These competencies are particularly important to foster in their own right, both pedagogically and professionally as one seeks to explore or articulate relationships and structures evident within data available for study (Lehrer & Schauble, 2000; Collins, 2011; NSF, 2007). **Therefore, our long-term vision is to develop computational construction kits that allow students to construct novel representations for live and complex data sets.**

Toward this long-term goal, we are currently exploring *dynamic representational competence* as one aspect of the data sciences that best exemplifies a "constructionist competency for the 21st Century". We use the term dynamic representational competence to refer to students' ability to design and interpret representations that 1) describe quantitative situations that vary over time, or 2) utilize time as a representational dimension (for example, use animation or interactivity to encode covariational relationships). The term is derived in part from diSessa and colleagues' work on representational and metarepresentational competence in children (diSessa et al, 1991; diSessa, 2004), which established that young learners possess a wealth of resources for constructing and critiquing representations of scientific and mathematical phenomena. We add the term *dynamic* to emphasize the new affordances that computational technologies provide for capturing and representing temporal aspects of quantitative phenomena (Moreno-Armella, Hegedus & Kaput, 2008). And, we also include in our definition a focus on the role that different situational structures and relationships play in students' representational decision making – that is, in how students might reach "beyond graphing" to communicate causal or structural aspects of a situation (Collins, 2011).

In this paper, we characterize how 7th grade students construct and describe static (paper-and-pencil) representations of dynamic situations. We use this as a way to identify beginning principles that will guide the design of Constructionist tools for young learners to create computational representations of such dynamic situations. Our ultimate goal is to create flexible toolkits with which young learners can invent these computational representations in order to explore and communicate trends in data they collect from educational probeware, computational sensors embedded in tablet and mobile devices, web-accessible data streams, and other data sources, share those visualizations with others, and test their representations with new and different sets of data.

Background

Our work is primarily and fundamentally motivated by a Constructionist theory of pedagogy (Papert, 1980), which emphasizes active construction of public artefacts for learning. In our case, we are interested in developing an environment to support students in the construction of computational data representation systems that can be shared, modified, and tested with different data streams or sets. We take inspiration from low-threshold data exploration environments such as TinkerPlots (Konold & Miller, 2005) and Constructionist tools that allow students to flexibly interface with sensors (Resnick et al, 2009; Sipitakiat, Blikstein & Cavallo, 2004; Erwin, Cyr & Rogers, 1999). We seek to contribute to this work a specific focus on dynamic representational and metarepresentational fluency as a specific learning objective.

Our motivating theory of learning is that students posses a wealth of experiential and intuitive "resources" – pieces of knowledge for making sense of the world – and that the process of learning involves establishing connections between resources that provide traction for solving a problem or making sense of a phenomenon (e.g. Papert, 1996; Wilensky, 1991; Noss & Hoyles, 1996). Hence, if we are to develop a learning environment to support dynamic representational competence, we much first identify young learners' existing strengths and approaches – what Bamberger (1996) calls the "simplest elements" (p. 34) that young learners attend to when constructing and describing their own representations of dynamic systems. The identification of these "simplest elements" is the goal of the present paper.

Research Question

What are the "simplest elements" (Bamberger, 1996, p. 34) that comprise students' ways of constructing and describing representations of dynamic phenomena? By "simplest elements", we seek elements that will simultaneously:

1. Characterize patterns in how students construct and communicate about representations.
2. Accommodate the diversity of normative and non-normative representations students produce to express situations involving dynamic quantitative change – including simple, complex, and statistical change.
3. Highlight points of intersection between students' normative and non-normative representational practices and constructions.

Methods

Our data sources include written classroom work and semi-clinical interview data collected from students enrolled in one of four seventh grade (age 12-13) classes at a diverse urban rim middle school in the Northeastern United States. We took this complementary "depth and breadth" approach in order to capture a diversity of students' ways of expressing dynamic situations, as well as to capture more detailed complementary data regarding the processes by which students develop and communicate about the representations they produce.

Both types of data were collected in the context of a two-day unit on "Showing Science Stories", developed in collaboration with the students' classroom science teacher Ms. Clemens[1]. The activity was completed in Fall of 2011 as an introduction to a physics unit on position-velocity graphs. The students had not yet had formal instruction on graphing during the school year in either their mathematics or science classes. In the spirit of the design-based research paradigm (Cobb et al, 2003), we did this in order to a) collect data that are true to how we might expect students to engage with this material during a typical school day, and b) explore how activities such as this can be integrated into existing curricula, since our ultimate goal is to design tools for use in classroom settings.

The Classroom Activity: Showing Science Stories

Our written data comes from worksheets that students completed during Day 1 of the two-day classroom activity sequence entitled "Showing Science Stories", led by Ms. Clemens. On Day 1, three "Science Stories" (adapted from existing literature, see Table 1) were placed on three different tables in the classroom. Students were split into groups of 2-3 students each, and each group was instructed to visit all three stations and decide how to "Show the story:" on their worksheet.

Type	Story	Original Source
Direct	A car is speeding across the desert, and the driver gets very thirsty. When he sees a cactus, he stops quickly to get a drink from it. Then he gets back in his car and drives slowly away.	diSessa, Hammer, Sherin, & Kolpakowski, 1991 (p. 125)
Emergent	Scientists are tracking a population of animals. For the first 15 years, the animals are doing very well – every year more animals are born than the year before, while the number of animals that die each year stays the same. However, after 15 years, a virus begins to spread through the population that	Blanton, Hollar & Coulomb, 1996 (p. 16)

[1] All names but the researchers' are pseudonyms.

	makes it harder for the animals to have babies. The number of animals that are born each year gets smaller and smaller until there the same number of animals are being born as are dying.	
Statistical	Some children in Massachusetts grew some flower plants. Soon after the flowers were first planted, they measured some of the plants to see how tall they had grown. There were many measurements, but the shortest plant was 20 mm high and the tallest was 80 mm. The children kept measuring the plants to track how tall they grow over the summer.	Lehrer & Schauble, 2004 (p. 643)

Table 1. "Science Stories" used for the classroom activity and interviews

For each "Science Story", the worksheet also included three questions:

- Why did you show it this way?
- What information did you think of when you showed the story this way?
- Do you know of any other ways to show this story?

A total of 46 worksheets were collected from students who consented to participate in the study. The worksheets were scanned, organized in Filemaker Pro for coding and analysis, and matched with corresponding student interviews when appropriate.

The Interviews: Communicating Representational Choices

While Ms. Clemens' class completed Days 1 and 2 of the "Showing Science Stories" activity, a total of 16 students (2 individual students and 7 pairs of students) also participated in more targeted semi-clinical interviews (Ginsberg, 1997) with the first author, Michelle. These students were identified with help from the classroom teacher as 1) likely to express their ideas verbally, and 2) representative of the diversity of socioeconomic, academic, and special education statuses of the larger class. On Day 1, these students completed the "Showing Science Stories" activity as part of the interview, on Day 2 they brought their completed worksheet to the interview.

Each interview was video recorded using two cameras to capture students' paper-and-pencil inscriptions and their interactions with the interviewer. The interviews lasted approximately 30 minutes and consisted of three phases. First, we asked students to show and describe what they created for each story featured in the "Showing Science Stories" activities, to discuss their representational choices, and to explain how they would instruct a classmate to show a different version of the story in the same way. Next, we asked each pair of students to create identical representations of a new story (about tracking the heights of different members of a family over time) without looking at one another's productions – in an effort to better understand systematicities in the way the young learners communicated about the representational system as they created them.

Analysis and Results

We present our results in three sections. First, we provide a general overview of the four "elements" of dynamic representation that we identified in students' descriptions and constructions of dynamic representations: (1) a *static setting*, (2) *objects* to represent quantities, (3) *features* of objects to indicate change, and (4) *rules* of behaviour. While not all four of these elements played a role for every student or every representation, we found that together they highlight patterns in the ways students created and described their dynamic representations, and accommodate the wide diversity of student productions in the study. We exemplify these elements in the second part of our findings by analyzing an in-depth example of an interaction between two students as they decide how to represent variable changes in the height of four family members (two children and two adults) over ten years. Finally, we provide evidence of these four elements in students' written work.

Part I: Defining the "Building Blocks" of Dynamic Representation in Young Learners

We found four "elements" that together characterize the diversity of ways that students described their representations of dynamic systems as they constructed them, as well as characterize specific features of their written productions. It is important to note that we are not making claims that these four elements represent different *types* of knowledge, but instead that they describe ways in which students differently attended to parts of their own representations. In this section, we use our interview data to supplement these descriptions of each element; Parts II and III include more detailed analyses.

Setting. Students often described, and included in their productions, a static "setting" or context-building scene. They described this setting as designed to help people who will see the representation to interpret the broad context of the situation within which quantitative change is taking place. For example, when we asked students how they would show a new story in a similar way to a story they had already represented (for example, how they would represent a new car story in a way similar to their existing representations of car stories), several suggested changing the setting to reflect a new context, while keeping other features the same.

Objects. Students also described active "objects" that represented quantities of interest within the representation. For example, multiple forms of cars, animals, plants, or abstract icons such as circles or bars would be used to represent quantities in the situation. Unlike the setting, students treated objects as though their form or position would dynamically change as corresponding quantities changed over time. Often, students explicitly labelled these objects to set them apart from the setting.

Indicators of Change. Objects changed to represent changes in quantities of interest or changes in time in a number of ways. Students would change an objects' form (for example, a plant would feature a bud to indicate earlier points in time and a bloom to indicate later points, or a car might include fewer or more "motion lines" to indicate changes in speed; see also Sherin, 2000), size (for example, bars were described as increasing in height with increases in quantity), location (for example, cars as well as bars or points on a graph, were described as moving over time even if represented multiple cars, points, or bars describing discrete points in time), or color.

Rules. Finally, some students included rules, usually in the form of sentences, which indicated how objects should change in response to further changes in quantity or time. While student's explicit inclusion or articulation of such rules were much more rare than settings, objects, and indicators, we include them as an element because they reflect a way in which students can build toward programming or training visualizations to dynamically respond to changes in data.

Part II: Evidence from Interview Data

In this section, we highlight how the elements we have identified "characterizes patterns in how students construct and communicate about representations of dynamic phenomena (Research

Question 1)”. We present a transcript of Irene and Alex, who are working together to create a representation of a story in which a family of four – a mother, grandfather, child, and baby – track their heights over ten years.

Figure 1. Irene and Alex

Setting the Scene. First, we see Irene and Alex negotiate what we are calling a *setting*: the static organizational and contextual elements of their representation that will help them define how objects within that setting that represent specific quantities should behave, and that will help others interpret the meaning of those behaviours. Irene proposes a conventional setting – a graph – but Alex instead proposes creating a “wall corner”, which his family and many other families use to track height over time.

[25:20.04]

Michelle: Ok, so this is how tall they are to start and I want you to think about how to show the ways that their heights change over the next ten years. So I'm going to put this up, but I want you guys to show it the same way, so try to communicate with each other about how you want to show the height.

Irene: Want to do like a graph for every person? Say how many inches they grow every year, but we already know that the mom has stopped growing.

Alex: Probably the grandpa. What my family usually does is that we mark our heights on the corner of the wall and then we date it...

Defining the Objects. Once Irene and Alex have settled on the wall corner as an organizational setting for their representation, they begin to negotiate the initial placement of objects within that setting – which are implied to be lines given the new context of height marks along the wall corner. Negotiating this initial placement also helps Irene and Alex determine scale, which they then use to determine later changes in the position of these objects over time.

[26:13.26]

Alex: so...there are lines down the middle and then lines for all the other people with dates.

Irene: You could have the first one be really tiny and say baby.

Alex: Well the baby is probably going to grow really fast

Irene: But it probably won't grow big fast like it will probably grow short in inches

Alex: I don't know...what year do you think for the baby?

Irene: I think maybe 2000, that seems pretty good...2000...and maybe the child will be twice the size of the baby.

Alex: Isn't it supposed to be taller than the mom...I guess...

Irene: Oh yeah, so we'd have to bring it up higher, so we could do...a little bit higher, but like a good size higher...like an inch higher...and then they're all the same year at once...and then the mom would be like a centimeter under him, right?

Alex: Like four inches...2000...and then the grandpa's the tallest?

Irene: Yeah, so he's like a high an inch about the child.

Alex: Only a half an inch? Isn't that only five foot five and a half? But I put him more towards the top, and then we put the baby a little taller...

Indicating Change Over Time. Next, Irene and Alex use these relative positions of objects to determine how those objects should change over time. Again, the setting has already provided enough interpretive context for the representation that Irene and Alex are both implicitly aware that objects shift only with respect to relative height. In Figure 2, we see that Alex represented this shift on the same “wall corner” line, while Irene drew a new wall corner to the left of the original.

[00:28:20.11]

Irene: And then we do another line...

Boy: For the baby, 2 foot four?

Irene: Have that be...baby...2002?

Boy: And um, how tall?

Irene: It's like that...doubled

Boy: Four feet? And what year is it?

Irene: 2002...and then the mom should stay the same...

Boy: So...just don't do anything...2000-2002

Irene: And then the child should be like you know how we drew the grandfather right there...halfway there:

Boy: Alright...5 foot 8 inches?

Articulating A Rule. Finally, Irene decides that rather than creating a new line for every two years, she can articulate a rule to describe how she expects the situation will continue to change “for everyone” over the next ten years. While the rule is articulated in terms of the situation itself rather than the representation, her references toward “the distance they’re measured” and the fact that the representation is “supposed to be charted until ten years” provide some evidence that she is including this information as a proxy for subsequent visual representations.

Irene: And then we'd have to do...we would write everyone...

Boy: Wait, what are we writing:

Irene: So write everyone but grandfather.. and mom grow two inches.. every year.. till how long?

[00:30:23.16] Irene: And then I wrote "everyone but grandfather and mom grow two inches until ten years"...

Boy: That's what this is supposed to show.

Irene: The distance they're measured is between ten years, we only did two years

Boy: You can't really chart growth...that's what this is supposed to show...

Irene: But we didn't show...she said in the story they're supposed to be charted until ten years...

Boy: Ok...

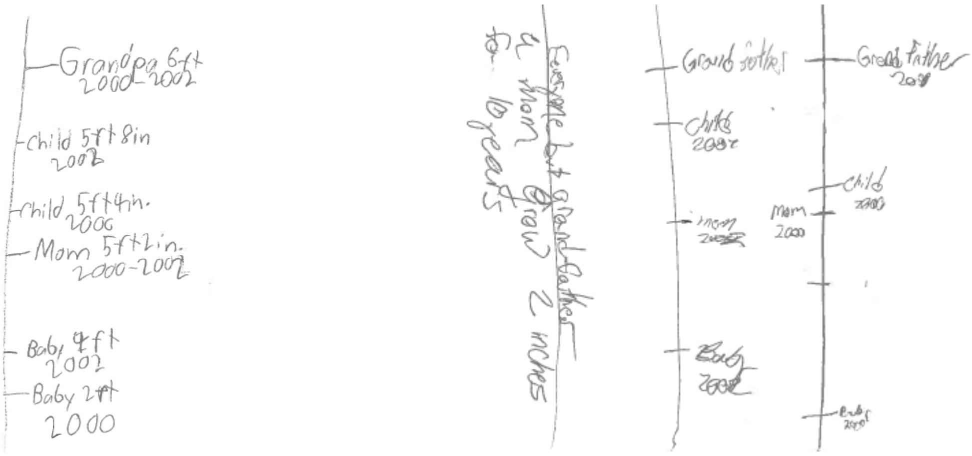
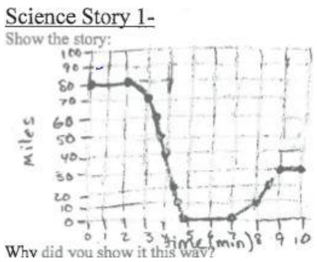
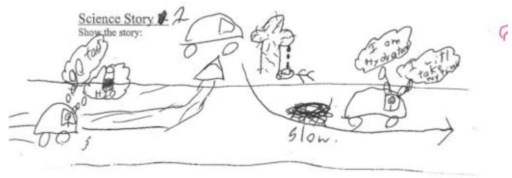
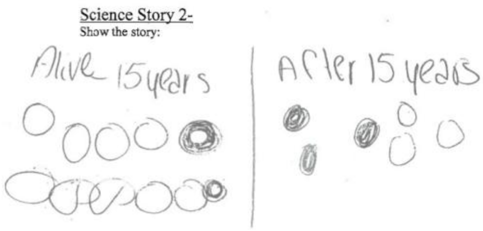
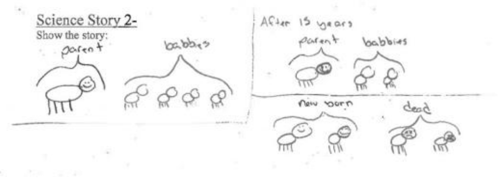


Figure 2. Alex's (left) and Irene's (right) work after creating representations of the family's growth over time.

Part III: Evidence from Written Work

Although the elements we have identified emerged from video data of students' interactions with one another and the interviewer, we have also found that they can be used to describe patterns across a diversity of students' written work (Research Objective 2). Below, we include samples of student work that are representative of the diversity of representations students produced for each story featured in the class assignment, and highlight evidence that our focus on *settings*, *objects*, *indicators* and *rules* can accommodate that diversity. We then report on more general trends throughout our entire corpus of data.

Direct Change: Car Story	 **1**	 **2**
Emergent Change: Population Story	 **3**	 **4**

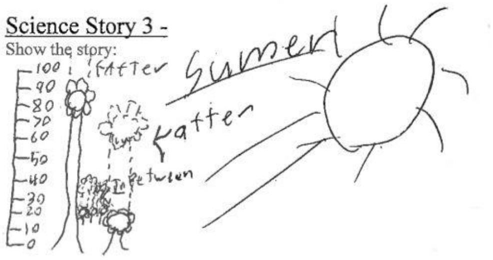
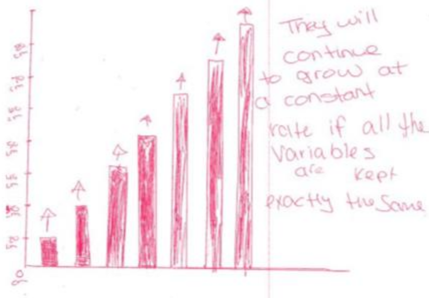
Statistical Change: Plant Story	 **5**	 **6**

Table 1. Representative Examples of Students' Written Work

Using the elements we identified in Part I, we can identify a variety of ways in which student productions (regardless of their level of alignment with normative representations of each situation; Research Objective 3) share a number of structural features.

Settings. The time/distance planes in [1], desert scene featured in [2], segmentation of space in [3] and [4], and axes featured in [5] and [6] all appear to serve the role of *setting*, establishing the context for the story and indicating how changes in focal objects should be interpreted (along which dimensions, and for which purposes). In [2], [5], and [6] these settings are especially evident because of their contrasts to elements of the representation that are shown the be changing: for example, the multiple positions of the same car in [2], dotted lines to indicate growth in [5], and arrows to indicate growth in [6].

Objects/Indicators. Points, circles, idealized figures, bars, are detailed drawings all serve the role of *object* in different representations. These objects change color [3], size [4, 5, 6], or position [1, 2] to indicate changes in quantities of interest as outlined in the story. In all of the representations featured here, only one object type is featured (that is to say, even though each representation includes more than just one object, they are all the same: multiple dots, bars, or animals for which only indicator features are changed). Often, however, students included multiple objects to indicate change: for example, a sun might be one object that becomes larger or its rays might become longer to indicate the passage of time at the same time as different plant objects indicate growth.

Rules. Though less common, some of students' written productions also articulated rules for how the representation (or represented story) accommodates times not explicitly featured, or times in the future. In the featured set of examples, [6] includes an explanation that the plants are expected to continue to grow at a constant rate.

In our entire collection of 127 representations, we found that all but 26 representations included features that we would associate with a setting. The average number of representations students produced featured just under 2 objects/object types each. 18 included verbalized rules for how the representation itself, or objects from the story to which the representation is meant to refer, will behave at times not explicitly featured.

Discussion

Computational technology has changed what we can measure, and how we can show information. This, in turn, is placing new demands on what is important to know about representational practice. We see *dynamic representational competence* - that is, students' ability to design computational representations that include information about change over time and feature animation and dynamism as a representational component - as an important Constructionist competency entering the 21st Century. In this paper, we take steps toward articulating patterns in the way that young learners approach problems of dynamic representation, in an effort to inform the design of construction kits that allow students to at once leverage these intuitive approaches, while also reflecting upon and expanding their own dynamic representational practice. The elements of dynamic representational competence that we have identified show promise as a way to articulate the structure of students' representational choices while taking into account a large diversity of situations that include dynamic quantitative change, as well as normative and nonnormative student expressions of that change.

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Make to Think: Ideas, Spaces and Tools

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Abstract:

The purpose of this essay is to share a learning experience research designed for, and developed by, an interdisciplinary group of faculty members of the University of Costa Rica. The proposal was put into practice in the form of a workshop, which used Scratch programming language and PICO Boards as an opportunity to model a constructionist learning environment. Powerful ideas, spaces, and tools were made available to the participants for the construction of digital stories, models, and simulations. The final goal was to enable the teachers to experience, through a hands-on experience, the environment, ideas, and tools of constructionist learning, so they could extrapolate them later on into their own fields and lessons.

Keywords:

Constructionism, Scratch, PICO Boards, Higher Education

Introduction

A workshop "Ideas, Spaces and Tools: Thinking by Doing" was an initiative of the Institutional Network for Faculty Training and Evaluation (RIFED, Spanish acronym) and the University Chair for Transdisciplinarity, Complexity and Eco-education of the Academic Vice-Presidency of the University of Costa Rica.

The initiative was designed for faculty members from various areas and disciplines, to the purpose of modeling a constructionist learning environment. Using Scratch programming language and PICO Boards (which will be explained further on), participants were able to design digital stories, models, and simulations, individually and in groups.

As will be presented further on, Constructionism is Seymour Papert's educational proposal for the creative use of new technologies in learning, involving communication, information and collaboration. The Scratch Language and PICO Boards are digital tools designed at the Media Laboratory (Media Lab) of the Massachusetts Institute of Technology (MIT), by the Lifelong Kindergarten group led by Dr. Mitchel Resnick.

As to learning models and simulations, these creations aim to illustrate scientific phenomena, obtain a better understanding of an observed phenomenon, or explain to other people specific ideas or data regarding a research (Colella et al, 2001). According to these authors, there are several types of models:

- Illustrative: those that show scientific processes or systems. For example: planetary orbits of the solar system, DNA chain models that can be manipulated to show the replication or transcription processes, or transparent human bodies showing internal organs. All these capture an angle of a scientific system or process, helping us to understand it in new ways.
- Analytical: based on mathematical equations, they enable the exploration of a variety of scenarios. For example, an economics professor could discuss a described supply and demand model by means of equations. Or a physics professor could want to do a model explaining how, in a given equation, position depends on acceleration and time.
- Simulative: instead of solving equations, the underlying mechanisms are described, letting them run through time to see what happens. These models can easily include random and probabilistic events, reflecting important features of the world that surrounds us. These characteristics of simulation models allow us to perform explorations difficult to achieve through analytical models, and impossible to achieve with illustrative models.

The “Ideas, Spaces and Tools: Make to Think” workshop was designed, planned and developed by an interdisciplinary group of faculty members, for the benefit of a faculty group also interdisciplinary. It was carried out on May 16-20, 2011, with the participation of 16 teachers from the following schools: Computer Science, Evaluation, Communication, Economics, Human resources, School Administration, Law, Sociology, Architecture, Mathematics, Chemistry, Medicine, and Geography and History.

The general purpose of the workshop was to enable the teachers to experience, through a hands-on experience, the environment, ideas and tools of constructionist learning, so that they could extrapolate them later on into their own fields and lessons.

On Constructionism: Make to Think

Based on the constructivist ideas of Jean Piaget and on Lev Vygotsky’s thought, the well known thinker Seymour Papert proposed Constructionism as an innovative educational vision on the use of digital technologies to support people’s learning. But far beyond this vision, Constructionism makes it possible to understand the way in which society and the individual take possession of digital technology (Papert, 1990). For the author, knowledge is something that is built in the mind, while something tangible, which must also be meaningful, is constructed in the physical world (Papert, 1990).

In this educational approach, Papert granted an active creative role to the apprentices, placing them as designers of their own projects and builders of their own learning. It is a question of empowering apprentices, so they can take on this active role. Opposed to computer-assisted instruction (CAI), which promotes that the computer teaches and programs the user, Papert proposed that the apprentice should be the one to program the computer, since by doing so, he/she acquires *“... a sense of command over an element of the most powerful and modern technology, establishing at the same time an intimate contact with some of the most in-depth ideas of science, mathematics, and the art of constructing intellectual models”* (Papert, 1987, p. 17-18). Papert maintains that the best learning will not come from finding the best ways to teach, *“... but rather from providing the students with the best opportunities to construct”* (in Fabel, 1990, p. 2).

These premises imply that people possess a natural ability to learn from experience, creating mental structures that allow them to organize and combine the information and knowledge built throughout their lifetime. According to Papert, knowledge is constructed in an especially fruitful manner when apprentices consciously involve themselves in a public construction, which may be exhibited, discussed, proved, examined or admired (Flabel, 1990, p. 2-3). In this sense, Papert warns that in order to do so, it is not enough to ask students to take charge of their own learning: they need to be equipped with the proper tools for them to do it.
Papert (1990) says that Constructionism is more than learning by doing. He states that it is doing with an intrinsic motivation; doing with the drive of personal values and desires; doing with an understanding of what is done. Above all, it is to take possession of knowledge; to make it one's own. According to Papert, this is finally achieved when the construction tools become invisible and the apprentice focuses on his/her own learning and knowledge.

On Two Powerful Ideas: Technological Fluency and Collaboration

A constructionist learning environment focuses on the exploration and construction of *powerful ideas*, as well as on their reflection and articulation (Papert, 2000). Powerful ideas are not important due to the place they occupy within a curricular framework, but rather because they give the apprentice the autonomy to approach a topic and study it in depth, by means of an actual construction process that puts it into context. Some constructionist learning tools enable the exploration of far-reaching powerful ideas: algorithmic thinking (Logo: Papert, 1987), decentralized thinking (StarLogo; Resnick, 1994), mentoring (MOOSE Crossing: Bruckman, 1998), moral values (Zora: Bers, 2001), collaboration and remix (Maloney, Resnick et al, 2010; Seneviratne, & Monroy-Hernandez, 2010).

The workshop in question took on the challenge of proposing situations in which the participants could experience some powerful ideas, and even the most powerful of all: **the idea of powerful ideas**. This time, two ideas in particular caught the general interest: technological fluency and collaboration. These two ideas not only constitute an important part of the learning process in which the teachers/apprentices were involved; they also nourished the design and development of the constructionist learning tools that were being used: Scratch and PICO Boards (explained further on).

Technological Fluency

Technological fluency refers to the use and appropriation of technological tools to do or construct a task; to create, communicate, and design. According to Papert's and Resnick's (1995) description, technological fluency involves much more than the ability to use technological tools, which would be equivalent to understanding some common phrases in a language. In order to be really fluent in a language (such as English or French), the person must be capable of articulating a complex idea or telling a "fascinating" story; that is to say, he or she must be capable of "doing things" with the language. Analogically, the concept of technological fluency not only implies knowing how to use technological tools, but also knowing how to build meaningful things using those tools. A technologically fluent person must be able to go from the source of an intuitive idea, to the execution of a technological project.

Moreover, technological fluency refers to the ability to program, which broadens the possibilities of what can be created, and what can be learned. It allows reflection on personal thought, and even reflection on the activity of thinking itself. For Resnick and the Scratch group, "… technological fluency means designing, creating, and remixing, not just browsing, chatting, and interacting" (Resnick et al, 2009, p. 60). This is why Scratch was created as a learning environment:

1) in a ground floor or with an easy access, meaning that its users can easily manage this constructionist learning tool, even if they have no previous experience in programming;
2) with a high ceiling, meaning that projects can become more complex as the users acquire experience and fluency with this tool; and
3) with thick walls, enabling the creation of different types of projects, involving people with different interests and learning styles.

Collaboration

The Scratch design, as a learning tool, is accompanied by its own website. The MIT Media Lab group that designed this tool is convinced that "… for (its) success, the language must be linked to a community where people can support, collaborate, criticize, and construct based on each other's work" (Resnick et al, 2009). Collaboration, besides being a powerful idea promoted from the Scratch design and experience itself, was essential to the workshop.

The interface of the Scratch learning tool was also designed with the goal of enabling collaboration. For instance, the page includes the "share" button, which means that a single "click" is needed in order to do so. Furthermore, when a person decides to share his/her project on the Scratch website, it is made available to all the other users. Apart from viewing it and getting inspiration from it, they can use it, reuse it, rate it, and assess it. This multi-channeled feedback gives shape, gradually, to a community, becoming one of the greatest motivations to create and share projects. Community members are continuously adapting and creating projects, based on the ideas of other members. The reuse and enrichment of projects is known as "remix". Information on how often and who has remixed a project is available at the site.

On the other hand, Scratch has been translated into more than 40 languages, raising collaboration to international level. The Scratch infrastructure not only favors its translation into several languages, but also accepts the use of any type of character.

In the workshop held at the University of Costa Rica, the participants worked in groups on the design and creation of their Scratch projects. They also had the opportunity to share their projects on the website, making them visible to the world at large. Some of the subgroups found their inspiration in projects available at the Scratch website, to conceptualize and design their own. In this occasion, and due to time restrictions, communication and feedback among participants was not carried out through the site, but rather in person. Each one of the subgroups had the chance to share their ideas, receive feedback from others, and reflect upon it so as to improve their projects. In addition, all of them could "borrow" ideas from the others, incorporating them into their designs.

On the Tools: the Scratch Programming Language[1] and the PICO Boards

As we mentioned above, both the Scratch Programming Language and the PICO Boards are digital tools designed by the Media Laboratory (Media Lab) of the Massachusetts Institute of Technology (MIT), by the Lifelong Kindergarten group led by Dr. Mitchel Resnick.

These tools inherit Papert's constructionist ideas and derive from previous proposals, such as the

[1] Scratch can be downloaded for free from the page http://scratch.mit.edu

Logo Language[2] and the programmable bricks[3], also from the Media Lab. Resnick and his group (2009) not only meant to provide new generations with powerful digital tools for learning, but also with an entire environment of mutual support and collaboration.

The Scratch programming language is based on professional programming languages specifically developed for young programmers, such as Flash/ActionScript or Alice 7and Squeak Etoys 5. However, its designers searched for a threshold that would make programming learning more accessible, offering a larger variety of options to develop logic-computational thinking. According to Resnick (2009), they designed a digital language more *tinkerable*, more meaningful and friendlier than other programming languages. For this reason, the Scratch language's grammar is based on a set of programmable digital blocks that assemble together, just as the physical blocks do when children and young people play with them. Scratch programmable blocks are designed to assemble only if by their joining they achieve a syntactical meaning. The language control structures (such as *repeat* and *forever*) are shaped as a C, indicating that the programmable blocks must be placed inside. The shape of the value-producing blocks depend on the value they return (ovals for numbers and hexagons for Boolean functions). The conditional blocks (such as *if*, or *repeat until*) have an incomplete hexagonal shape, indicating that a Boolean function is required.

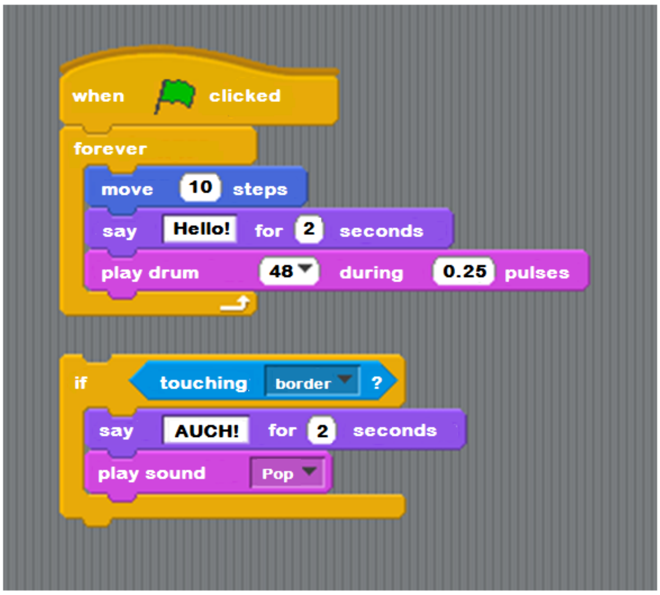

Figure 1. Examples in Scratch programming

Besides being a programming language, Scratch also aims to satisfy the diversity of learning styles. That is why it promotes its use among programmers who plan in a vertical way (from top to bottom), as well as among those who prefer to tinker with a thought and plan from bottom to top. In like manner, the programming activity of this language consists of mixing graphics, animations, pictures, music, and sounds.

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[2] Commercial versions of the Logo Language, known as LogoWriter and MicroWorlds.

[3] Commercial versions known as MindStorms and PicoCrickets

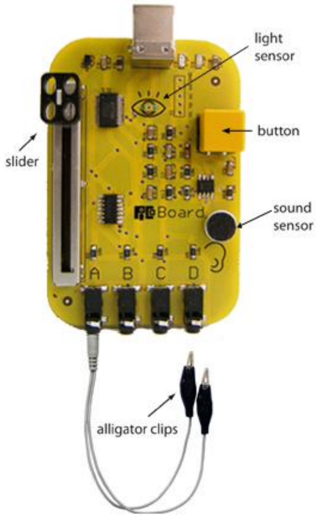

Figure 2. Picoboard

The PICO Boards (Fig. 2) are electronic cards that allow Scratch-programmed projects to interact with the physical world, by means of light and sound sensors. They also have a slider that controls the value of the entries (resistance), a button that reacts to contact, and a pair of loops that detect when the cards are connected. Therefore, these cards allow projects on the screen to react before stimuli (light, contact, resistance, or sound) coming from the outside world, making them interactive.

On the Workshop's Design and Development

The design of a constructionist educational activity requires previous and careful planning, in order to guarantee a reference framework that is solidly supported and, at the same time, very flexible. This combination of conceptual solidity and methodological flexibility is what grants complexity to the constructionist design of a learning environment. But only through careful planning is it possible to accommodate emergents and active participation from all the people involved, without running the risk of promoting a senseless activism. In this context, and in agreement with Papert's ideas, "objects-to-think-with" must be available; and the construction of meaningful projects on the part of the participants constitutes the fundamental strategy of learning. Hence the workshop's name (title of this paper): thinking by doing.

With these ideas in mind, the workshop included a dynamic combination of lectures about powerful ideas (regarding Constructionism, as well as on the potential of the Scratch language and PICO Boards); demonstrations; guided exercises; design and construction of individual and group projects; and sessions of reflection and reconstruction of the experiences and learnings (Fig. 3). The title "Ideas, Spaces and Tools" was chosen because it reflects the workshop's educational spirit or vision: to create a space where the encounter between ideas and tools could become a reality.

The Workshop was carried out at a computer lab of the Department of Computer and Information Sciences (ECCI, Spanish acronym) of the University of Costa Rica (UCR), lasting four days (Monday 16, Tuesday 17, Thursday 19 and Friday 20, May 2011). Each day, the four-hour work blocks (1:00 to 5:00 p.m.) were separated by a short recess and refreshments. Since the workshop dates was held close to the celebration of the World Scratch Day (May 21, 2011), it was entered as part of Costa Rica's Scratch Day activities.

Figure 3. Working sessions, of the organization team

The workshop was launched with an introduction called "The Workshop's Spirit", which included a Scratch project to describe the purpose of creating a space where all participants, apprentices and mediators alike, would have the opportunity and tools for "thinking by doing" as a team. Scratch, PICO Boards and construction materials (including waste material) were presented as the tools which would enable them, in this case, to think and do together, so as to find ways to improve university teaching (Fig. 4). Constructionism, collaboration, technological fluency, and the creation of models, simulations, and digital stories were presented as ideas especially placed in this space, to encourage innovation in the university learning environments. In other words, the educational vision of the workshop was briefly presented at this stage.

Figure 4. Construction materials and PICO Boards

Immediately after, there was a first demonstration of the basic operation of Scratch, followed by a period of free exploration of Scratch projects, included in the original gallery of this programming language. The second and third days began with similar demonstrative sessions, covering the operation of the PICO Boards and useful capsules of programming concepts. The "Sensorboard 1 Sunrise" project was used to demonstrate PICO Boards, taken from the examples on motors and sensors originally included in Scratch, which includes a cottage built with cardboard and waste materials (Fig. 5).

After the Scratch free exploration period, a group dynamics was carried out, collecting the first impressions and initial ideas of the participants. This first encounter turned out to be vital within the programmatic logic of the workshop, to the extent that it allowed the creation of a propitious and evocative atmosphere. Moreover, it enabled participants and facilitators to find convergent interest lines and specific expectations for the development of the workshop. The exercise was intentioned, aimed at targeting a contextual construction of the reality shared by the set of participants. In Resta's words, "behavior, thought and content are the bases that structure teaching and learning – at least in what pertains to organized teaching –. These structural elements become accessible by working on the design of 'authentic' realities in the classroom practices" (Resta, 2004, p. 184).

The proposed problem-inducing node aimed at discussing the different expectations held by the participants regarding the workshop. The development line was designed in terms of a possible project or topic, and its expected impact on the teaching evolution of each participant. Apprentices were asked to write down their answers on a piece of cardboard, all of which were then adhered to the blackboard. Once their answers were displayed, discussion started to the purpose of gathering common ideas, mainly those related to the three thematic areas: digital stories, simulations, and models. Participants analyzed different ideas, enriching the discussion and enabling the appointment of work teams, for the process developed throughout the week (Fig. 6).

Figure 5. PICO Board demonstration

Figure 6. Team work discussion

Powerful ideas were presented on the first and second day, followed by an open plenary session. The topics developed followed thematic lines broached and discussed from the start. Likewise, new theoretical-practical enrichment axes were presented: technological fluency and collaboration, their current importance, and the manner in which they appear in Scratch. As was mentioned above, the spirit and intentionality in the design of this training space was the construction of a formative scenario, which would enable the apprentices' immersion into a constructionist environment.

This environment would be innovative in nature, by developing a setup with non-traditional elements for an interdisciplinary group of faculty members. Although Scratch, the tool, represented an important appeal, it was always assumed and promoted as a cognitive medium that allowed different interaction levels. In Papert's words, it became an "*object-to-think-with*".

Cabero described it as: "In short, what we want to say is that the system's technical determiners will not be what mark its quality and efficacy, but rather the attention we pay to the educational and didactic variables put into operation. Nowadays, problems are not technological, but derived from knowing what to do and how to do it, and why we want to do it" (Cabero, 2006, p. 8).

Four work teams were formed at the end of the second day, granting them a period to start planning a group project with Scratch and PICO Boards. Days 3 and 4 were mainly devoted to the development of these projects. Two groups focused on the development of simulation projects, while the other two created digital stories.

Due to the workshop's constructionist approach, the groups shared their learnings after each work session, through dynamics where each group showed the others their ideas, progress, and difficulties. This favored a greater exchange of ideas and learnings among the participants, based on a process of reflection upon the work developed in the projects. Closing each day with a reflection and reconstruction period on the process experienced was equally important.

A demonstration on the way to integrate the international community of Scratch, by means of its webpage (www.scratch.media.mit.edu), was performed at the end of the workshop.

The projects developed by the participants were shared with the international community through this means.

On the Findings

Although the technological tools played an important role in this workshop, let us recall that they always did so as objects-to-think-with. The goal was to try out and reflect on a constructionist learning environment, as an educational alternative to traditional university teaching.

Expectations and First Reactions

Most of the participants started the workshop with the following expectations: to discover innovative forms of education, realistic and applicable in their courses; to discover new ways to approach knowledge, for both them and their students; and to acquire more instruments to make their lessons more attractive, by allowing the students to lead the knowledge construction processes. Participants were asked to express their first reaction with a short phrase. Some of their answers were:

Knowing by doing

A return to wonderment

Programming through play

I fill like I'm stuck (not too much) at the threshold of an interesting adventure.

Nevertheless, some of the people enrolled placed their expectations on technology itself, on learning to use it so that it would help them to continue teaching their students in the traditional way.

Assessment

At the end of the workshop, and by means of an online survey completed by 14 of the 16 participants, different angles of the workshop were evaluated.

The majority (78%) considered that the objectives set out in the program were accomplished.

Likewise, the majority (93%) expressed that the contents learned during the workshop were relevant for their teaching work, while 86% felt that they could adapt what they learned to mediate in their students' learning.

Regarding the participation and organizational aspects of the activity, most participants (86%) considered them satisfactory, and a similar percentage (85%) was pleased with the work carried out by the facilitator team, expressing that they would recommend this workshop to other faculty members.

The less appreciated feature was the physical space; only 35% thought the physical space was appropriate for the execution of the activity. The placement of the furniture, computers, and other equipment did not favor the visual traffic or movement of the participants, and their rearrangement to accommodate small groups or plenary sessions was difficult.

The general rating of the workshop was positive; in a scale of 1 to 10, 43% rated it with a 10, 21% with a 9, 21% with an 8, and only 14% marked it with a 7 or lower.

The survey included an open section for observations and suggestions, opinions summarized as follows.

In general terms, the enthusiasm and good opinion expressed by the participating faculty members show a favorable reception and satisfaction levels. Their appreciation regarding the elements surrounding the dynamics, the thematic pertinence, and the results were rated in a positive way. On the one hand, many of their thoughts were gathered during breaks, as well as during the presentation of their projects. The general opinion was that the workshop offered a set of ideas that they could develop, in a similar manner, in the classroom with their students. Thus, the workshop's original objective was reached: to model with a view to subsequent implementation in the participants' specific learning environments.

Figure 7.Simulation project in progress

Figure 6.Digital story group discussion

In other cases, participants were mainly concerned with finding some follow-up means to continue working as they did during the workshop. There was a general feeling concerning the need to have participation and experimentation spaces for the teachers, a non-traditional element in their routine at the University of Costa Rica.

This factor is especially important, since it poses new lines of development towards future complementary projects. These should be considered in the logic of the network structures already developed within the Institutional Network for Faculty Training and Evaluation (RIFED), among others.

In like manner, one of the participants expressed dissatisfaction on most of the aspects assessed, justifying it by saying that:

"There was no support material for the tool itself; it is as if someone said, we're going to do an Access workshop, the tool is there, now use it and discover how. That is not the way to do it."

Since the workshop design included continuous support on the part of the facilitators, by means of demonstrations and one-to-one work, complemented with support materials on the Scratch tool available online, this comment was interpreted as a reaction to the habit of participating in traditional learning environments, more structured, more linear, and usually based on theory. In this case, the participant did not understand nor accept the constructionist vision.

In general terms, a percentage of people are expected to react defensively facing innovations, for they prefer the comfort zone of the familiar.

One of the workshop's more positive results was the type of projections expressed by the participants following the experience, documented by means of interviews. For instance, there was a case in which the workshop enabled a person to find in Scratch the necessary tool to study the development of peace processes among young vulnerable local groups, as part of a Ph.D. research. Several participants recognized in Scratch a tool they want to use, to help programming students with their studies. Though the workshop did not restrict itself to presenting Scratch and its operation, but rather its use to enable the immersion into a constructionist environment (as was previously explained), the knowledge and identification of the tool is still worthwhile, due to its use in different contexts.

The interviews complemented the survey data, agreeing in the favorable opinion of the participants and the acknowledgement of a new way to learn, as can be seen in the following comment:

"The workshop was very interesting; it makes you feel free to create. And they kept their promise: it has changed my perspective on learning."

In short, it is valid to say that the UCR faculty members who participated in this constructionist experience positively assessed the execution of this kind of activities, not just for the reasons mentioned above but because it promotes the interaction between teachers from different disciplines and academic units, and for the level of freedom to learn and create offered by the constructionist approach.

Acknowledgement and Recognition

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The Technicity Thesis: a constructionist proposition

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Abstract

Constructionism entails learning by constructing objects open to inspection, which Papert claims is the most felicitous means of learning. This begs many questions. The cornerstone question is: How is the human capable of constructing objects? The keystone question is: How does this make learning most felicitous? An answer to both questions is offered by the proposition of a small, unique information processing adaptation in the human brain. The term 'technicity,' is adopted to denote this source of the human capacity for technology (and art). Information entropy at this source is far lower than that of environmental sensory input. The consequence is that technology is both simpler and more powerful than biological organisms. Mentally constructed, the concepts derived from the technicity adaptation are shown to be more congruent with properties of matter than are perceptually based concepts for which language is the evolved communication medium.

Keywords

Information, entropy, human evolution, technology, art, concept formation, primary school, Logo, body syntonicity, turtle geometry.

Introduction

This paper is the culmination of a decade of work on the technicity thesis. The trigger was certain behaviour by children with learning difficulties that raised the question: How do humans draw? This generalised to the more general question of technology and art, on which science was silent. Like the dark side of the moon, it appeared perceptually inaccessible. The first step in developing the notion of technicity, the linking of feature detector neurones (Hubel 1995) with drawing, was presented at Eurologo in Portugal. In Warsaw, the square/diamond effect offered supportive evidence that also called into question language primacy. Paris saw a more developed hypothesis based on the more recent understanding of the role of prefrontal cortex, a matter of interest in primary and special education (Ó Dúill 2010). Plausible though this proposal was in terms of the "how" of constructionism, it did not explain "why" it was felicitous. The cornerstones were in place but there was no keystone to hold the edifice together. For this the concept of 'entropy and information' (Stonier 1990) was required. This is used further to develop the technicity thesis.

Working from first principles, genetic, neurological and informational knowledge is assembled to offer a new perspective on human evolution. Key is recognition that information available to the genotype is of a different quality from that available to the phenotype. The former is of lower entropy, thus more powerful. The mechanism proposed in the earlier papers, reprised below, makes available this information to cognition. The thesis explains why technology is both simple and powerful. It precisely defines the difference between scientific and naïve concepts; and demonstrates this by the square/diamond effect. The secondary intellectual quality of language is also revealed, leading to reconsideration of Vigotsky's (1962) ideas on thought and language.

Most work used in developing the thesis has reached the realms of non-specialist science. Key sources include Lewin (1998), human evolution; Streidter (2004), brain evolution; Fuster (2008), prefrontal cortex; Dawkins (1989, 1999), genetics. The thesis is contrasted with the social brain and language theories (Dunbar 2004a, 2004b) and triangulated against current views on human evolution (Mellors 2007); child development, notably in drawing (Anning and Ring 2004); but mainly against the everyday experience of teachers and parents in the primary school years.

The Technicity Thesis

Technology is simple. Biology is complex. This is the conundrum. Simplicity is of low entropy: it requires little information to fully describe something simple. The 'second law insists that it is not possible to reduce entropy without doing work, without the expenditure of so-called free energy. Given that biological processes all increase complexity and thereby entropy, the appearance of low entropy entities, such as purified red ochre, associated with the earliest human, appears to be physically impossible. The Neanderthal, with a larger brain than modern humans and with very similar neurological architecture, signally failed to develop anything recognisably technological.

A critical distinction needs to be made between creating technology and making things, including tools. There is a discontinuity between animal artefacts and human technology. Animals construct their artefacts according to genetically determined templates. The result is that their constructions are species specific. The test for genetic templates is stasis over time. The tool assemblage of the Neanderthal remained unchanged for hundreds of thousands of years. Pigment production, whilst characteristic of the human and thereby a species identifier, has not remained static.

Seeing red

Isolating a pure primary pigment like red is not trivial. The signal processing overhead required to extract red from the image at the retina would be very high if noise removal were used. This is not the evolutionary approach. Colour vision is an early adaptation. Fish, as children know from the classroom aquarium, have a very good colour sense. The underlying mechanism is the same in goldfish as in the human, though its location and scale differ. Hubel (1995) and colleagues first described this mechanism in primates, referring to the neurological structures as “blobs” from their histological appearance. These computational units are necessary because the receptors in the retina cannot fully resolve light into spectral colours, a consequence of the photochemicals used. Information on light colour is lost in the chemical reaction a photon energises in a receptor. The result of that reaction is a nerve impulse. A nerve impulse is not an analogue of sensation; it is a symbol. From a computational perspective, it is a symbol on a Turing tape with no intrinsic meaning. The meaning of the symbol emerges only when it is read by the machine and causes a change in its state. A symbol may only cause a change in machine state if a machine already has information about its meaning. This implies that information about the redness of red is built into the nervous system. That information about photons of 470 THz frequency, primary red, is built into the brain raises the question of its origin.

The source of the information is the genotype, not the environmental experience of its phenotype. This solves the entropy problem. Evolutionary processes work in geological time, not lifetimes. Genes have had aeons in which to incorporate information on properties of matter in their four-base code. A little reflection shows that they incorporate a very great amount of such information in order to build the body of thr phenotype. The evolution of distance senses required the genome to have information about the medium used and to express that information in a suitable structure. Such structures are a function both of the property of matter to be discriminated, e.g. pressure in sound waves or photon frequency, and constraints of neurone function: the excitatory/inhibitory character of synapses in particular. In colour vision this leads to a system that generates a form of false colour rendering of spectral colours, which bends the spectral segment that is visible light back on itself to form a circle with non-spectral purple. The system defines a colour space by the opponent pairs: red/green, blue/yellow and black/white. In this way, photon frequency becomes a means of differentiation (red fruit contrasts with green leaves) and is incorporated into instinctual behaviour. This implies that all animals, including the human, with the same photon identification system 'see' a 470 THz photon as "red" in the same way. This does not imply that they all have a concept of red. For red to become a concept rather than a percept, it is necessary that information on pure unassociated colour be made directly available to cognition.

Neurone nature

Neurones are metabolically expensive informavores. Their representation increased in response to environmental complexity; in hominines at the expense of the gut. This implies that a capacity to model the world is adaptive. In mammals, neocortex evolved. This makes social behaviour and planning possible and inhibits instinct. Birds have a homologous structure. Prefrontal neocortex underwent the greatest relative expansion: from some 3% in the cat through 17% for chimpanzees to 27% for the human (and Neanderthal). In hominines, overall brain expansion was from some 450cc in chimpanzees to a Neanderthal maximum of over 1400cc. Expansion was accompanied by invasive connection of prefrontal neurones to most other parts of the brain. This is the means by which prefrontal cortex performs its executive function; modulating and moderating actions of the older brain; and manipulating memory from neocortex, motor and sensory, to create new possibilities from historical information: to plan for the future and to modify that plan in the light of experience. Over-production of neurones and connections is considerable. Both are pruned, leading to the loss of some 50% of neurones and connections by adulthood; neurones that receive no input die. Aggressive invasion by imperialistic prefrontal neurones turned out to be adaptive. There is no reason why this process should have ceased by the time that the Neanderthal, human and Denisovan shared a common ancestor, somewhere in the region of half a million years ago. The stage is now set to consider the adaptation that led to the human capacity for technology.

Creative connections

The technicity thesis proposes that, in the human, prefrontal neurones invasively connected to primary sensory cortex and its homologues thereby making available to cognition the information the genome expressed there and the manner of its structural expression. Such structures are active neurone circuits. They may be activated either by sensory input or by a probe from elsewhere. No teleology is involved; an ongoing neurogenetic process of expansion simply ran into a new class of information. When manipulated by the prefrontal cortex, the result was the creation of novel cognitive entities and these turned out to be adaptively advantageous. The proposed change in neural connectivity is shown schematically in figure 1.

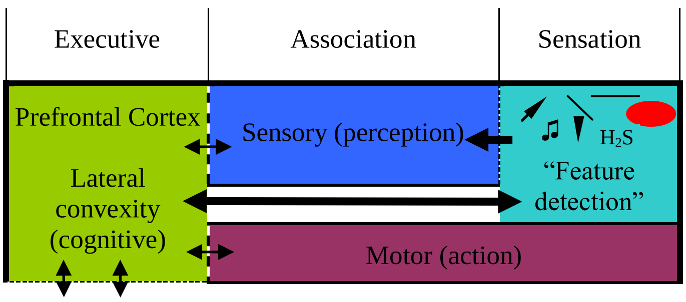


Figure 1. The architecture of the technicity adaptation. Extension of prefrontal neuron connection to the genomic information available in primary sensory cortex (arrow passing through the unshaded area) may be compared with the normal sensory-perceptual route (connections through the blue shaded areas). The type of information made available by the technicity adaptation from so-called feature detector neurons is illustrated symbolically. Note the reciprocal connectivity to the rest of the brain from prefrontal cortex and extensive connection between its cognitive and affective divisions.

That humans consider purple to be a colour, suggests that these neurone circuits are the source of colour concepts. The question now becomes: What other information might be available from this neural structure? The list includes: line length and angle and direction of motion in primary visual cortex, pitch in primary auditory cortex. The human ability to identify and blend notes to make perfumes and flavours in cuisine suggests olfactory bulb connections. There may well be others. For the present discussion, only line length and angle, the foundations of geometry, are needed.

Conflicting concepts

Linear cut-mark designs on bones are taken as an early sign of human behaviour. The Platonists identified geometric shape as an aspect of ideal form. Such activity is based on the composition of line length and angle information in prefrontal cortex. One ideal shape, the square, can affirm Papert's proposition about the felicity of construction. The shape may be physically constructed by folding; a straightedge and compass; or turtle commands, repeat 4 [fd (number) rt 90]; none of which are orientation sensitive. Now consider figure 2.

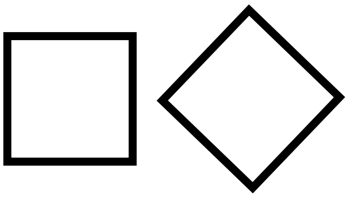


Figure 2. The square/diamond effect demonstrating the conflict between V-concepts and T-concepts. Both shapes are products of technicity and both are square, but the characteristics of the perceptual system lead to the perception, and naming, of two distinct objects.

Both shapes consist of pairs of equal length equidistant parallel lines intersecting at a right angle: a square. But the one-eighth rotation of the leftmost brings to mind a different, distinct form and name: diamond. At one level there is a single concept with a single verbal description; at another level two different linguistic concepts exist. Scientifically, they are the same cognitive construct, a product of technicity sourced from line orientation information in primary sensory cortex. Only when processed by the visual system does orientation becomes an issue; the result of perceptual artefact. Whilst this form is unique in generating the effect, it signals a general conceptual issue: the well documented divide between science and naïve perception. As the physical construction of a square and its rotation, and inspection of the effects of rotation, can overcome the perception of two objects in figure 2, so technicity-based constructs overcame the strong perception that the sun revolves around Earth.

Why is the technicity adaptation more powerful than perception and language? The answer lies in relative entropy, which the square/diamond effect helps clarify. The square is described only by equality of side and angle, as the turtle geometric formulation demonstrates. The square/diamond effect includes orientation. Less information is needed to describe the technicity construct than to describe the perception-derived concept. It is, therefore, of lower entropy. Recalling that the brain is a physical system, Carnot principles show the technicity concept to be the more powerful.

The effect also demonstrates the weakness of language noted by Papert. Rotating produces the effect and resolves it: two perceptual, verbally-denoted concepts resolved into one. In so doing it produces a conflict with language. This is to be expected. Language, which serves perceptual processes, was fully evolved before the human technicity adaptation arose. Technicity, though the more powerful cognitive capacity, is verbally inarticulate and consequently must convey thought through constructed physical forms: Papert's objects open to inspection. Here lies both the power of the technicity adaptation and the difficulty of its verbal communication.

In technicity contexts, language lacks the means of expression and new terms must be coined. In this case the word "concept" has ceased to be adequately expressive. It is proposed to resolve this by prefixing. Concepts originating from the technicity adaptation will be T-concepts. Those that arise by normal perceptual processes become V-concepts. The T denotes technicity as the source of the concept and honours Alan Turing (Ince 1992) whose thinking helped their identification. V denotes the perceptual/social/verbal nexus that is the foundation of these concepts and honours Lev Vigotsky (1962) who first described their formation. The crucial difference between the two is that a V-concept may be accepted because of its internal linguistic consistency but a T-concept is consistent with the behaviour of the physical world; to which technicity uniquely provides the human with cognitive access. Some differences between these two qualities of concept are shown in table 1.

T-concept	V-concept
Technicity based (genomic)	Perception based (experiential)
Non-linguistic (constructed product)	Verbal (internal and spoken utterance)
Low entropy (simple and powerful)	Environmental entropy (complex)
Species level (universal)	Culture level (specific)
Tested against properties of matter	Tested for cultural consistency

Table 1. Some differences in quality between T-concepts and V-concepts.

As an aside, it may be noted that, although only indirectly derived from language, mathematical formulations must also be proved against the real world.

Art and aesthetics

Prefrontal cortex has two divisions, affective and cognitive. The relationship between the two is described by Damasio (2006) and Fuster (2008). The effect is to give art and technology the same foundation, the difference being largely in affect: the constructions of the technologist have less affect when perceived that do those of the artist. However, at the creative construction stage they both entail control over the properties the materials employed. In order to play a violin concerto it is necessary to compose the music, using pitch information from primary sensory cortex, and build a violin using craft knowledge of wood and fibres. Science can describe the relationship between string length and pitch but evocative sounds rely on the craft exercise of technicity.

Triangulating technicity

The technicity thesis is a proposition designed to be tested for congruence with reality; merely to be plausible is insufficient.

Child development and activity in kindergarten and primary school are by far the best sources of evidence, thought little regarded by constructionists. By the age of eight, as figure 3 shows, the basic information that the technicity adaptation provides has begun to be combined into complex representations, though the purity of that information still shines through in simple geometric constructions and primary colouring. The drawing shows the use of mental processes that are also present in the structure in language. If these forms do not originate from the technicity adaptation, how does an immature mind extract them from sensory input, from environmental information?

Figure 3. A drawing by an eight year-old girl, illustrating the composition of primary-sensory-sourced information to create an aesthetically pleasing and expressive communication.

The earliest signs used to identify the presence of the human include pigment processing and the presence of points and other geometric microliths used to make component-built tools. There is no evidence that the larger-brained Neanderthal ever progressed beyond the standard Mousterian tool assemblage even when coexisting with the human. Neither is there evidence of artistic ability nor of any ability to organize living space (Findlayson 2010).

The mechanism proposed for the technicity adaptation is consistent with current knowledge in the fields of genetics, brain evolution and the role of prefrontal cortex. That the technicity adaptation comes on stream during the years of elementary education, from infancy to puberty, is consistent with the finding that prefrontal maturation takes place during this phase and is highly influenced by experience: hence the universal importance given to primary schooling.

There has long been the issue of the gulf between the “two cultures” of the sciences and arts (or humanities). This was categorised in terms of cocktail party conversation by Snow (1963) using Shakespeare and the Second Law as exemplars. In selecting Shakespeare, Snow placed the focus on the socio-linguistic domain, which has great evolutionary depth. This contrasts with the fruits of technicity, which are recent and have only secondary linguistic representation.

Finally, there is the issue of entropy. Technology is of far lower entropy, defined in both physical and information terms, than biological phenotypes but is commensurate with that of genes. This means that technological forms created from this information have greater power than those that originate from perception: simple T-concepts are more powerful than complex V-concepts.

Summary

The economy of the technicity thesis is greater than its alternatives: language and the social brain. Some elements from which technology and art are constructed, and against which the verbal (and mathematical) hypotheses of science are tested, are listed in table 2.

Colour	Line	Motion	Pitch	Chemical
Pigment Art Spectrum Photons	Shapes Architecture Writing Geometry	Projectiles Choreography Machines Entropy	Tone Music Time Relativity	Flavour Cuisine Molecules Particles

Table 2. Some sources of genomic information expressed in neurone circuits and behavioural correlates.

A cognitive consequence of the neurological architecture of technicity is an additional quality of concept. Directly sourced from low entropy information, T-concepts provide the entrée to science through technology and moderate social V-concepts derived from verbal-perceptual experience.

Technicity and linguistic thinking: T-concepts vs. V-concepts

Thought, from a technicity perspective is not language. T-conceptual thinking, by definition, is non-linguistic thought. In the case of music, dance, games, visual arts, architecture, mechanical and electronic design and production, and mathematics, the involvement of language is minimal: reducing to injunctions such as, “Do it like that.” Scientific enquiry is different. Academic means of communication are largely verbal. Conceptual frameworks shared between peers are expressed in language. Testing of scientific concepts is carried out, however, not against rigorous linguistic formulations, as is the case with philosophy and mathematics, but in terms of congruence with physical reality. Thus, the foundation of science is the technology devised to verify new ideas. Old ideas expressed in language and based on established perceptual processes are resistant to change because they fit the current view of reality. Advances in science appear to be outlandish when first proposed, even to eminent scholars: vide Einstein and quantum theory. Acceptance of scientific ideas, however unreasonable they might appear to V-conceptual thought, comes about because they work out in practice. This cognitive conflict explains the time needed for scientific ideas to take hold and the difficulty that many people have in accepting them. The V/T concept division may also lead to misconceptions, particularly where a large intellectual investment has been made. In the constructionist community there is a nice example of this process at work.

LOGO and Turtle Graphics

At the time the microcomputer entered the primary school classroom there was much discussion about its role: tool, tutor or tutee. For the present, the first is dominant. Papert, with a computerist background, was as much concerned with the programmability of the medium and its potential, as he saw it, to catalyse the early development of Piagetian formal operational thinking. LOGO, as a formal programming language might offer a means to this end. Work with the button box and the floor turtle suggested an entry point for young children of kindergarten and primary school age.

The simple ‘forward, back and turn’ commands to this small robot spawned turtle graphics and its academic big brother turtle geometry. Turtle graphics was simply the name for turtle drawing. Its academic variant offered educational kudos: a flexible relative geometry to complement the rigid frame of Cartesian coordinates. Turtle geometry (Abelson & diSessa 1980) was new math. Papert saw it as a means of inculcating mathematical thinking at primary school level. At another time in another place, it might have become a carefully researched PhD project. At the time, however, it was a poorly researched vehicle for getting computer science ideas into primary education. When primary school teachers expressed concerns about the subject matter in relation to the shape and space curriculum they taught, they were condemned as conservative and obstructive. A culture of questioning the professionalism pf primary school teachers made this appear not unreasonable.

Both Papert (1981) and the authors of Turtle Geometry reported so-called bugs in the children’s thinking. Three classic bugs are shown in table 3 along with their associated explanations. These explanations seem reasonable and have an authentic mathematical and computer science feel. The suggested general solution was to “play turtle” to get the idea of heading. Teachers tried this with children moving paper arrowheads in different orientations. Papert went further and proposed that if children “Walked Turtle” a cognitive phenomenon that he called “body syntonicity” would lead to the internalising of the concept of heading and the ability to describe shapes in “Turtle Talk”. However, experience in the primary school classroom with turtle graphics suggested that there was a problem of greater cognitive depth and the idea of body syntonicity was questionable.

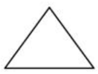
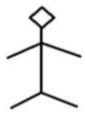
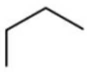
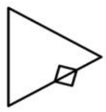
	Triangle	House	Man
Target			
Outcome			
Explanation	Thinking about the internal angle of the shape rather than the “heading” of the Turtle	Failure to realise that an “interface” procedure is needed to place the Turtle in the right state to draw.	Solved by breaking the drawing into procedures for the parts and then combining them, but see the house bug.

Table 3. The turtle geometric bugs reported in Mindstorms and Turtle Geometry.

Body syntonicity

Papert expressed the idea of body syntonicity, derived from Freud’s ego syntonicity, as follows:

> “*The Turtle circle incident illustrates syntonic learning. This term is borrowed from clinical psychology and can be contrasted to the dissociated learning already discussed. Sometimes the term is used with qualifiers that refer to different kinds of syntonicity. For example the Turtle circle is body syntonic in that the circle is firmly related to the children’s sense and knowledge about their own bodies. Or it is ego syntonic in that it is coherent with children’s sense of themselves a people with intentions, goals, desires, likes, and dislikes. A child who draws a Turtle circle wants to draw the circle; doing it produces pride and achievement.*

Turtle geometry is learnable because it is syntonic." (*Mindstorms* p.63)

This argument is a linguistic one based on observation and analogy. The notion is V-conceptual. When referred to physical reality it is seen to conflict with the childhood development of drawing which is instrumental. The constructive processes of technicity make shapes, like the ones played with in infant posting boxes and in kindergarten. The child has a concept of circle already in mind, the earliest scribbles are circular. It follows that stepping around a circle and describing the action is but to create a mnemonic to link to the programming language. Papert's linking with the aesthetic is, however, entirely consistent with technicity and is highly educationally important.

Rotating squares

Unqualified hindsight is of little value, but when informed by a new perspective can help to guide thinking. On the preceding page of *Mindstorms* is the illustration in table 4 column two. Rotating figures was a pastime that mathematics educators liked because it emphasises the invariance of the form, illustrates symmetry and is aesthetically pleasing. The rotation here is 120°, the angle of turn for the turtle triangle. Papert suggests other angles be tried, illustrating the shape produced by 36°. A turn of 45° (table 4, column 3) is not mentioned. The shape is disturbing, dissonant. Conceptual conflict arises from V-conceptual perceptuo-linguistic effects. It is perceived as two different figures and not as the same one rotated. It feels anti-mathetic. When repeated eight times the figure in column 4 is generated. Here diamond and square vie for dominance.

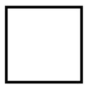
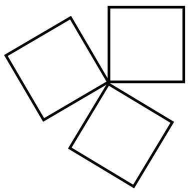
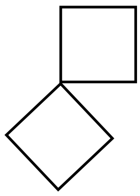
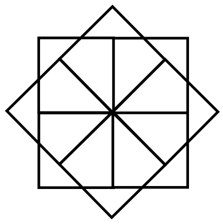
to square repeat 4 [fd 50 rt 90]	repeat 3 [square rt 120]	repeat 2 [square rt 135]	repeat 8 [square rt 135]
			

Table 4. Rotations reported in Mindstorms and the square/diamond rotation.

Do we see the mathematician's search for pattern and symmetry subconsciously overlooking the dissonance? Did educational philosophy and mathematical evangelism misdirect critical thought? Whatever, the need for new ideas to be rigorously tested against reality is shown in stark relief.

Education

It should be obvious that the technicity adaptation imposes the requirement for education on the human. T-conceptual products of technicity do not derive from a genetically specified capability as do animal artefacts and communication, including human language. They cannot be activated and refined by immersion in the social milieu. Epistemological processes are required to transmit and increment knowledge generationally. These matters are discussed in a companion paper.

Conclusion

A thesis is useful only if it illuminates cognitively dark corners, suggests further research, and (preferably) has immediate application. Technicity fulfils all these requirements and more. The instruction/construction distinction hinted at by Papert is given a sound biological foundation, and, fittingly for the conference location, the Platonist's question concerning the redness of red is given an answer; and geometry, as written over the Academy door, takes on new meaning. Most importantly, however, the cognitive complexity, so frequently passed over, of the primary phase of education is thrown into sharp relief – to the possible embarrassment of academe.

Nobody expects the second law of thermodynamics to appear at a conference as mathematically oriented as Eurologo; but it has now. Entropy underpins technicity, the evolutionary adaptation unique to the human and the source of the species' technological capability and artistic ability. It is the power behind constructionist educational methods. It offers both prospects and discomfort.

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Gestures as a tool of semiotic mediation in 3d turtle geometry environment

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Abstract

In this paper we report findings from a design-based research aiming at shedding light on the way eleven-year old students used gestures while constructing mathematical meanings in the framework of a 3d Turtle Geometry Environment. The results bring in the foreground the role of gestures, as signs that mediated the mathematical notions integrated in the computational environment, as well as the interconnection between gestures and the embodied turtle metaphor. Different kinds of gestures were used by students depending on their focus point during the construction processes. When focusing on turtle's navigation and the graphical results of this navigation, students used dynamic representational gestures. On the contrary when viewing 3d space or 3d objects as external observers they used abstract deictic or static representational gestures.

Keywords (style: Keywords)

gestures, turtle geometry, embodied metaphors

Theoretical Background

The study of gestures is a rather new field of research in mathematics education (Radford, 2009), which is investigated through various perspectives. In this paper the focus is set on the way students at the end of primary school used gestures in the framework of constructionist activities in a 3d Turtle Geometry computational environment. Gestures are investigated as a special mode of embodied expression and communication and as a tool of semiotic mediation of the learning process, which -in conjunction with other modes of expression- can shed light on the processes of mathematical meanings construction (Arzarello et al., 2009).

According to the socio-cultural theory of learning people's interaction with the real world is defined and formed through the use of symbolic objects and cultural tools (Vygotsky, 1978). In this framework gestures are investigated in their semiotic perspective, on the way they function as signs that mediate people's interaction with their environment in specific cultural contexts (Radford, 2005). In particular, in mathematics education gestures seem to acquire new dimensions (McNeil, 2000) and are thought as a means of knowledge objectification, as a means that can help students realise the notions integrated in the various mathematical objects (Radford, 2009). A special interest is aroused in cases that digital technologies are used, where certain actions are conceived as new kinds of gestures, e.g. pointing with the mouse or 'dragging' of hot spots in Dynamic Geometry computational environments (Kaput, 2005). On the one hand gestures are related to the task to be accomplished and on the other hand they may be related to the mathematical knowledge that is to be attained. Gestures are usually contingent to the situation determined by the solution of a particular task but they can also play a rather pivotal role in promoting the evolution of signs from idiosyncratic to culturally determined and crystallised mathematical signs. The relationship between digital technologies and knowledge is complex (Bartolini Bussi & Mariotti, 2008) and a careful analysis of the evolution of gestures used by students (among all the other signs) can offer a new perspective on the access that students have on the embedded in these artefacts mathematical knowledge.

In parallel, the intimate relationship between the functioning of the brain and body experience (with or without the use of tools) even when the most abstract mathematical notions are considered is now commonly recognised. Concepts are imminent in each concrete realisation of experience and in its relation to other experiences. Nemirovsky (2003) argues that 'thinking is not a process that takes place 'behind' or 'underneath' bodily activity, but it is the bodily activities themselves'. Thus, gestures are investigated as a window on the embodied aspects of meaning construction processes (Anastopoulou et al., 2011), as an interface between abstract and symbolic mathematics and mathematical metaphors (Kim, Roth and Thom, 2010) that are on their part grounded on human sensorimotor experience and action (Lakoff & Nunez, 2000). Research interest has also arisen recently in relation to the role of gestures while students are constructing geometrical figures in 2d (Latsi, 2010) and 3d Turtle Geometry (Morgan & Alshwaikh, 2009) computational environments. These studies provided empirical support for the embodied means used by students in their effort to carry out particular geometric tasks highlighting the connections of certain gestures with the integrated in the aforementioned digital tools mathematical knowledge while raising questions about the interpretation and use of the same gestures by different groups of interlocutors.

In the research presented here our pedagogical aim was to engage the students in navigating a moving entity, the turtle, to construct graphical digital objects through Logo programming. Research seems to conclude that carefully designed 2d Logo- based microworlds are an effective medium in offering rich mathematical experiences and encouraging the construction of meaning through the turtle metaphor (Clements & Sarama, 1997; Kynigos, 1997). Navigating the turtle requires the formation of essentially novel methods of spatial orientation, where the reference point is not the position of the user's body but the turtle's body, relative to which the entire system of orientation may change. In this framework body-syntonicity is a critical concept in 2d Turtle Geometry (Papert, 1980) that refers: a) to navigating the turtle by coordinating one's body-posture, physically or imaginary, with the turtle-vehicle of motion and b) to solving geometrical problems drawing upon ones embodied motional experiences. Recent extensions of Turtle Geometry in 3d space do not offer just a new perspective in the teaching and learning of geometry. New issues are raised related to the way the turtle metaphor is put to use and the way deeply rooted intuitions about experiencing space and locomotion can be exploited so as to make sense of geometric notions (Kynigos & Latsi, 2007, Morgan et Alshwaikh, 2009). In particular our research aim was to investigate: a) students' gestures and their role in mathematical meanings construction in the 3d simulated geometrical space and b) the way these gestures are related to the central metaphor in the 3d Turtle Geometry environments, turtle as a moving entity with which the user can syntonise his/her body.

The computational Environment

MaLT is a constructionist microworld environment that extends 'Turtleworlds' to 3d geometrical space. 'Turtleworlds' blends Logo based Turtle Geometry with tools to dynamically manipulate procedure variables and observe the resulting 'continuous' change to the respective figural constructions (Kynigos et al, 1997). In MaLT, we used a well established method to extend Turtle

Geometry to 3d by adding two kinds of turn commands (Reggini, 1985): 'UPPITCH/DOWNPITCH n degrees' ('up/dp n'), which pitches the turtle's nose up and down on a plane perpendicular to the one defined by right-left turns, and 'LEFTROLL/RIGHTROLL n degrees' ('lr/rr n') which moves the turtle around its own axis. A second feature of MaLT is that we kept the 'Turtleworlds' feature of variation tools. These tools recognise the procedure responsible for any figural construction and afford dynamic manipulation of variable values resulting in DGS-style change in the figures. A third feature also affords dynamic manipulation but this time what is changed is the users' viewpoint of the Turtle Geometry space: a) in a toggle fashion by using buttons to pick among 3 default views (front, side, top-down) and b) by dragging a specially designed vector tool, which we called 'the active vector', where the user can define the camera's direction or position. Thus MaLT combines: a) interactivity, b) multiple interlinked representations and c) dynamic manipulation and dynamic visualisation of the 3d simulated space.

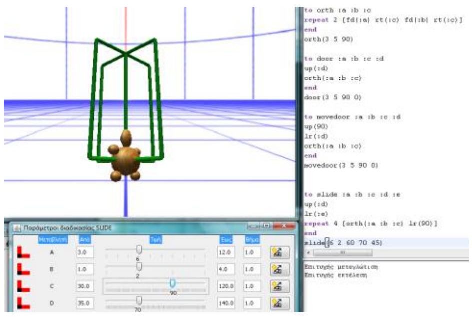


Figure 1 .The MaLT computational environment

Methodology

Espousing an interpretive approach in educational research (Cohen et al., 2007) in the study reported here we followed a design-based research method (Van Den Akker et al., 2006), which entailed the 'engineering' of tools and task, as well as the systematic study of both the process of learning and the means of supporting it (Gravemeijer & Cobb, 2006). A critical component of design –based research is that the design is conceived not just to meet local needs but to advance a theoretical agenda, to uncover, explore and confirm theoretical relationships, to create new theoretically expressed understandings about areas for which little is known. Thus, the analysis we have carried out does not comprise any kind of quantification of qualitative data, but rather refers to a non mathematical process of interpretation, carried out for the purpose of discovering concepts and relationships in raw data and then organizing these into a theoretical explanatory scheme.

The research took place in the 6th grade of a public primary school in Greece. The class consisted of 23 pupils, who had totally sixteen 45 minutes teaching sessions with the experimenting teacher over two months. The pupils didn't have any previous experience with 3d Turtle Geometry environments but they were accustomed to 2d Turtle Geometry. The pupils worked collaboratively in mixed-gender groups of two or three in the school's computer laboratory. The tasks were designed to bring in the foreground issues concerning the mathematical nature of 3d geometrical objects through their dynamic manipulation and transformation in mathematically meaningful ways. In this research paper we present and analyse data taken from the first two tasks of the activity sequence that lasted 4 teaching sessions. In the 1st task the pupils were asked to navigate the turtle in such a way so as to simulate the take-off and the landing of an aircraft while in the second one they were asked to construct rectangles and to position them in at least two different planes of the simulated 3d space, so as to simulate the walls of a room.

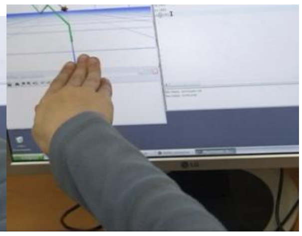
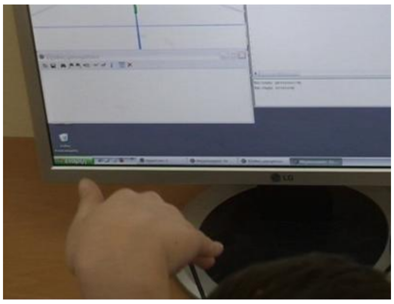
In order to describe the pupils' learning trajectories as they happened in real time we adopted a participant observation method in data collection while the main corpus of data included video-recorded observational data, the experimenting teacher's observational notes as well as the sorting and archiving of the corpus of the students' work on and off computer. As far as the students' work on the computer is concerned we used specially designed screen capture software -called Hypercam- which allowed us to record students' voices and at the same time to capture all their actions on the screen. Trying to attend to the full range of the communicational forms that students used in the meaning-making process in data analysis we followed a multimodal discourse analysis method viewed through a social semiotic lens (Jewitt, 2009). Initially data were transcribed in a multimodal way focusing on students' situated choices of resources rather than emphasizing on the system of the available resources. In an attempt to overcome the limitations presented by a sequential organisation of data and to present simultaneously multimodal phenomena, matrices with columns were used. As a unit of analysis we used the 'multimodal episode'. The multimodal data were divided in episodes that constituted easily discernable parts of children's actions and interactions with a clear focus point (Noss & Hoyles, 1996, p. 148). Thus 'multimodal' episodes do not represent some quantifiable entity but are chosen to represent clearly the kind of activity that was going on in specific time in the classroom. As episodes have been extensively used as a unit of analysis in the framework of qualitative researches, the term multimodal has been added so as to stress that the episodes used in our analysis do not rely only on oral or written language but comprise also gestures, visual images, instances of students' symbolic work on and of computer etc. The results presented here are based on the work of one group, consisted of one boy and one girl, while focusing on the way gestures were used during the construction processes.

Gestures as a means of semiotic mediation

Use of gestures and turtle's navigation

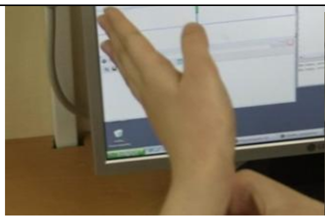
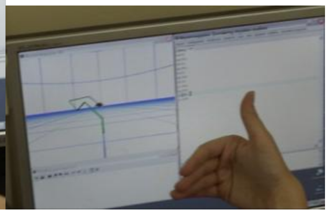
It follows from the data that while the students were trying to navigate the turtle in the simulated 3d space they basically used two kinds of gestures: a) dynamic representational gestures and b) abstract deictic gestures.

It seems that the 'play the turtle' metaphor (Papert, 1980) cannot be realised physically as far as the 3d Turtle Geometry environments are concerned: In these environments the turtle moves in all the 3 dimensions without any restriction while in the real 3d space the human body can only move in a 2d horizontal plane. As a result students used extensively their palm so as to represent the 3d entity and its orientation as well as its motion in the simulated space. The palm was used as a 3d object analogous to the computational turtle, as it has distinct 'place' characteristics, up-down, forward-backward and right-left, it can be moved in all the three dimensions, while it is easily manipulated and observed. In the following episode the students are trying to decide how to carry on the turtle's journey in the 3d simulated space during the first task using a series of dynamic representational gestures. The use of the palm seems to contribute to the visualisation of a series of successive spatial representations before these representations are systematically articulated either verbally in everyday language or symbolically through logo code. Thus gestures were used as a link to the embodied turtle metaphor that underlie Turtle Geometry environments and as an intermediary stage between lived experience and institutional signs such as Logo code. Moreover these gestures seem to provide the context in terms of which students verbal expressions are to be interpreted. It is indicative that the students' utterances cannot be understood if not accompanied by the respective gestures.

S2	Now, do you know what we should do? As it is like that, to turn it this way and to move it forward.	 
S1	Not to move it down a bit?	

Episode 1: Dynamic representational gestures

In the present research the palm was not used only representationally but also deictically to indicate the turtle's direction in the 3d space. In the following episode which took place during the 1st task, the students are trying to decide how many degrees the turtle should turn so as to take the intended position and direction. As the focus point is not turn's direction but turn's measure, the palm is rather used as an indication of the various turtle's position for certain angular turns in the 3 space and in particular for the left turn of 45, of 90 and of 135 degrees.

S1	Fine. We will turn it. Wait it is like that. So half of it, approximately 45, 90, approximately at 135 …	  

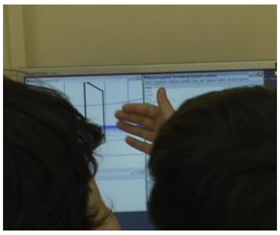
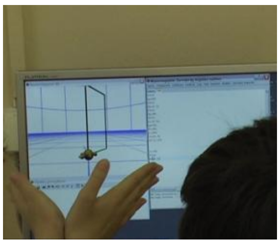
Episode 2: Abstract deictic gestures

It should be stressed that the students' palm was not used deictically as far as certain concrete objects or attributes of the context of the activity are concerned, but that these gestures integrated abstract deictic characteristics. Children's gestures rather exhibited geometrical knowledge and helped students cope with the abstractness of certain mathematical concepts such as angular turn in 3d simulated space. These abstract deictical gestures called for mathematical interpretation and implied a metaphoric use of the real space, where certain angular measures had acquired spatial properties. The aforementioned kinds of gestures - as well as the kinds of gestures that are presented in the next section- are here considered as signs that were invented and used by the students as an auxiliary means of solving the given tasks while using the specific digital tools. On the one hand these gestures are related to the accomplishment of the task and on the other hand they are rather related to the mathematical content that is to be mediated bringing in the foreground the complex relationship between digital tools, task and mathematical knowledge.

Use of gestures and 3d graphical objects' construction

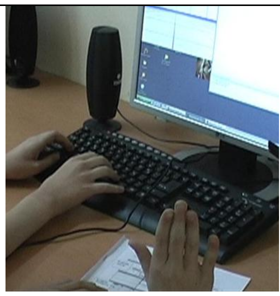
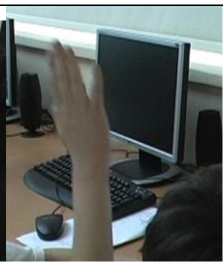
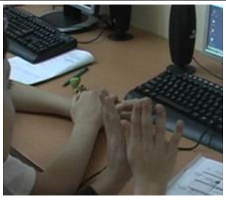
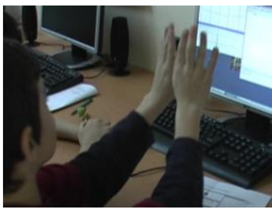
It follows from the data that when the students' focus point was on the construction of 3d graphical objects, two kinds of gestures were used: a) static representational gestures and b) dynamic representational gestures.

In the following episode the students are trying to translate their intuitions in visual representations so as to represent geometrical figures and their orientation. The gestures that are used could be considered as representational gestures as they have a degree of resemblance to the desired geometrical figure. In the following episode that took place during the second task, while trying to match real to corresponding virtual 3d objects, the students are using firstly the one palm to represent the position and direction of the one wall/plane that they want to construct in the 3d simulated space. Then, the intended figure and the spatial relationship between the two walls/planes are represented through the use of both palms. So the palms seem to be used as intermediary transitive objects between the real object and its figural representation on the computer screen. This kind of gestures rather depicts spatially encoded knowledge and helps students conceptualise the spatial relationships that should be then expressed in Logo code.

S1	Now as it looks this way, let's make the one wall like that.	
S2	Yes that's better.	
S1	Otherwise we can do it this way.	

Episode 3: Static representational gestures

The representational gestures used in the previous episode could be characterised as static, as they constitute static instances of the intended figures. While the children were trying to move along from static 3d representations to their design through the turtle's navigation another kind of representational gestures was noticed: dynamic representational gestures. This kind of gestures seems to represent the 3d object not as a static instance but as a result of the turtle's motion.

S2	Up (90). From this to go this way.	
S1	The staircase should rather be this way and not that way.	 
S2	What? Will we do it straight?	
S1	Of course.	
S2	It should move this way. Then it should turn. … rt, no. No, there is something else, how is it called? This way and then this way.	   

Episode 4: Dynamic representational gestures

In the above episode the two students are discussing about the way they should construct a staircase in the 3d simulated space of MaLT. It was a task that was carried out by the students spontaneously at the end of the second task and while they were waiting for the other groups of students to finish their constructions. Initially student 2 suggests turning the turtle up 90 degrees while representing this motion with his hand. The other student having focused not on the turtle's navigation but on the staircase's inclination in relation to the horizontal level corrects the former showing with his palm the inclination that the staircase should have, which in any case should not be vertical to the horizontal plane. S2 reacts asking if they should do the staircase straight, understanding the other student's gesture as a straight inclined line. Then, he represents both the turtle's motion and the staircase moving his both palms. The palms side by side represent the horizontal and vertical planes of the staircase, while the hands' motion seems to represent the turtle's motion in the simulated 3d space of MaLT. In parallel he tries to translate verbally in Logo code the turtle's motion trying to find out the right turn order saying indicatively: *'Then it should turn. ... rt, no. No, there is something else, how is it called?'*, looking apparently for the 'downpitch' order which corresponds to his hands' motion. It is rather interesting that the spatial arrangement of the plane's as well as the angular turtle's turns are initially represented visually and kinaesthetically and then verbally. The use of gestures was an alternative sign, an alternative way of embodying and organizing information that the student was not able to express in purely verbal or formal ways. It should be stressed that these situated gestures denoted the intended figure not so much pictorially but through actions and as a result of it while playing a mediating role between internal, subjective imagery and shared conventional logo code.

Conclusions

In the present research gestures were understood as signs/symbols that mediated the mathematical knowledge integrated in the computational environment (Radford, 2009, Arzarello et al., 2009). Gestures were used in order to objectify, to attribute meaning to mathematical contexts and contents interpersonally and intrapersonally. A virtual gesture space was created in front of the students as a result of the use of gestures, where the various represented mathematical objects were placed, processed and interconnected. This virtual space was 'endowed' with mathematical meaning that was accessed and visualised kinaesthetically. Thus, gestures rather provided an intermediary stage between real and computational objects that fostered imagery focusing on images' structure rather than on accuracy (e.g. the exact degree of turtle's turn) that rather reduced some of the cognitive load of problem solving. In parallel, gestures offered a context without which students' verbal expressions could not be interpreted.

The gestures that students used seemed to have helped bridging the cap between abstract mathematical notions and sensorimotor experience. In the present research gestures were conceived as a way of revealing unconscious aspects of concepts formation, while certain kinds of gestures were rather strongly related to the embodied metaphors that underlie Turtle Geometry environments. Dynamic representational gestures were used not only in order to represent the turtle's motion through a series of successive spatial images but also in order to represent 3d geometrical objects as a result of the actions of a moving entity. Moreover, it follows from the research that the students used different kinds of gestures according to their point of focus. While they were focusing on turtle's navigation through body-syntonicity and the graphical results of this navigation, the students used dynamic representational gestures. On the contrary while they were observing 3d space as external observers and not through the turtle metaphor they used either abstract deictic or static representational gestures. The kind of gestures used in the various phases of geometrical objects' construction processes could rather be integrated in the broader research interest on the perceptions students have in 3d virtual environment (Hauptman, 2010) and the spatial dimensions of interactions though 3d avatars (Petrakou, 2010). Highly visual 3d Turtle Geometry microworlds, such as MaLt, seem to influence not only the kind of geometrical problems posed to students but also and most importantly the way students interact with the medium and the solution processes followed by them (Hollebrands et al., 2008; Jones et al., 2010). In this framework gestures serve for students as signs that mediate mathematical activity and knowledge and for researchers as a window that offers a new perspective on how learners think and talk about mathematics.

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"Metafora" and the fostering of collaborative mathematical problem solving

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Abstract

The learning of problem-solving strategies and heuristics in mathematics has been recognized as of utmost educational importance. Yet, this learning heavily relies on capitalizing on metacognitive abilities which turn the learning of mathematical heuristics to a challenge that involves fostering metacognitive processes. CSCL researchers have posited that collaborative situations and technology-based environments, which allow construction of artefacts and discussion upon them, may support teachers in facilitating small group work in classes. In this paper, we claim that this general approach can be adopted in the case of mathematical problem solving. We show how several teachers used a new platform – the Metafora[1] environment, and how their experience acquired in a workshop, helped them designing activities for their students. This process is exemplified through the case of one teacher and one mathematical challenge designed to foster central mathematical heuristics in collaborative settings. Besides the potentialities of this approach we list major obstacles in this design research program.

Keywords

Mathematical problem-solving, heuristics and learning strategies, collaborative learning, CSCL environments

Learning to solve problems has been defined as a major educational goal in mathematics education (e.g., Schoenfeld, 1992). However, serious obstacles have been detected over the years concerning the ability of teachers to facilitate the learning of problem-solving strategies and heuristics in classroom. The scaffolding idea, according to which teachers' interventions are tuned and calibrated to students needs, is rather complex when it comes to the learning of meta-cognitive competences. The adoption of a pedagogy based on small group learning turns this complexity to an insurmountable challenge. However, CSCL (Computer-Supported Collaborative Learning) tools are intended to facilitate the activity of agents in collaborative contexts. This article presents a platform, and adequate pedagogy, designed to support collaborative mathematical problem-solving by proposing tools for small groups of students in

[1] http://www.metafora-project.org/; The Metafora project is co-funded by the European Union under the Information and Communication Technologies (ICT) theme of the 7th Framework Programme for R&D (FP7), Contract No. 257872 "

order to solve mathematical problems, learn about their own use of cognitive constructs and to help teachers facilitate group work.

Metafora is an online CSCL system aimed at enabling groups of 2-5 students, 12- to 16-year-old students to participate in inquiry/problem-based activities in science and mathematics, in collaborative settings. Collaboration is a tool for scientific and mathematical activities. However, it is also a goal as students Learn How to Learn Together (L2L2), with their teacher and the software scaffolding. The aim in Metafora is then twofold as students learn scientific and/or mathematical inquiry strategies or heuristics and at the same time, learn general techniques related to collaboration.

Metafora includes a planning/reflecting tool – a shared space with which groups of students collaboratively, and autonomously, construct plans and reflections upon their work. This is being done by a creation of a set of icons called "Visual Language Cards" – a closed set of graphical ontology for scaffolding the construction of on-going plans and reflection on them. The ontology is based on models of inquiry-based learning (e.g. Tamir, 2006), and of problem-solving (e.g. Polya, 1945). As shown in Figure 1, the ontology organizes the collaborative problem solving: Finding hypotheses, simulation, discussion, etc. Also, it serves to monitor actions in order to carry out plan, and to revise the on-going plan in order to adapt to outcomes obtained so far. The visual language also represents scientific/mathematical moves: understanding the problem, reflect, simulate, etc. Naturally, the visual is understood to help gaining control (monitoring and regulating) over actions. From the beginning of the project, the visual language was envisaged to serve as a reflection tool affording students' conscious on-line and post mortem active construction of models of their collaborative mathematical problem/challenge solving process (Hamilton, Lester, Lesh, & Yoon, 2006). Needless to say, the twofold goals aforementioned cannot be attained in a short term period but in a succession of well-designed activities.

In addition to the planning tool, the Metafora platform includes different tools such as LASAD – a graphical tool for facilitating argumentation by the construction of a discussion-map, and other microworlds tailored for specific activities to simulate scientific or mathematical processes (described as "resources" in Figure 1).

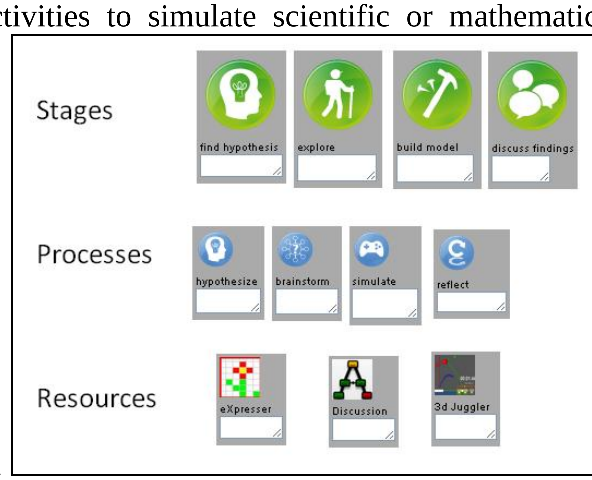


Figure 1. Examples for three of the visual language elements. 1. Stages of the problem solving 2. Processes undertaken during these stages, 3. Resources used to solve the problem

Metafora presents several obstacles to teachers (Abdu, DeGroot & Drachman, 2012). First, its pedagogy is based on challenges – difficult problems with solution processes that is not straightforward, and as such takes more than one lesson to solve. Second, the format of the course – a succession of scientific or mathematical activities, does not lend itself to be easily inserted in existing curricula. Third, teachers are asked to integrate various software when they design the challenges. And last but not the least, students are envisioned to collaborate in small groups, and it is notoriously difficult for teachers to promote and support learning in such settings (Webb, 2009; Schwarz & Asterhan, 2011). In spite of these difficulties, when we advertised our initiative in schools, many teachers showed their interest. Seemingly, a role of mentoring in challenging based activities seemed to some of them more interesting than a role of transmission of normative knowledge.

Methodology

We adopt a *participatory design* methodology in which four science teachers and two mathematics teachers participated in a workshop to prepare themselves to deliver year-long courses in mathematical problem solving and physics. We explained to the teachers the purpose of the design of Metafora and its use. The teachers then solved a challenge in the context of the Metafora environment. Consequently, they adopted a critical approach toward the tool and tried to find ways to improve Metafora for facilitating collaborative problem solving. We videotaped the teachers and transcribed their actions.

In the following sections we present an example for a math challenge, show how one group of teachers solved it in the Metafora environment, and how the experience of one of the mathematics teachers led her to design a problem that is appropriate to the level of her students. More elaborated findings on the development of problem solving heuristics and collaborative heuristics will be reported in further publications.

An example of challenge: The gardener

The Gardener challenge is formulated this way:

> *A gardener wants to create flowerbeds in the form of strips surrounding a central rocky rectangular lot so that (1) the area of the flowerbed is equal to the area of the rocky lot; (2) The central lot and the flowerbed form altogether a rectangular lot whose sides are parallel to those of the rocky lot; (3) the width of the strips is constant and (4) all dimensions (lengths, widths) are integers.*

For junior high-school students as well as for university students, this activity is quite a challenge. The problem is rather open, since while it is relatively easy to find some solutions, it is very difficult to come up with generalized solutions. This challenge provides then many opportunities to implement and/or to learn problem-solving strategies (e.g., Arcavi and Resnick, 2008, Arcavi 1994). For example, in the version that we adopted, no figure is available with the formulation of the challenge, so that sketching a figure becomes a problem solving heuristic (Pólya ,1945) to be learned or to be applied. This absence of figure leads solvers to first understand the problem through by the creation of a sketch of the lot, and to create several examples of flowerbeds. In contrast with school tasks in which variables are already chosen by the designer, representing the challenge algebraically is a heuristic move (Pólya, 1945).

Solving the Gardener in the teacher workshop

In the first step of the study, a teachers' workshop took place in the computer lab. One computer was available for each teacher, but teachers often sat around a common computer. We will now describe the work of a group of teachers, Tsurit, Arnon, and Yael that engaged in the introduction phase and in the Gardener during a session of two hours and half. Their map was constructed progressively while they solved the challenge. Figure 2 displays the outcome that served as a tool for on-going plan and reflection upon the work done.

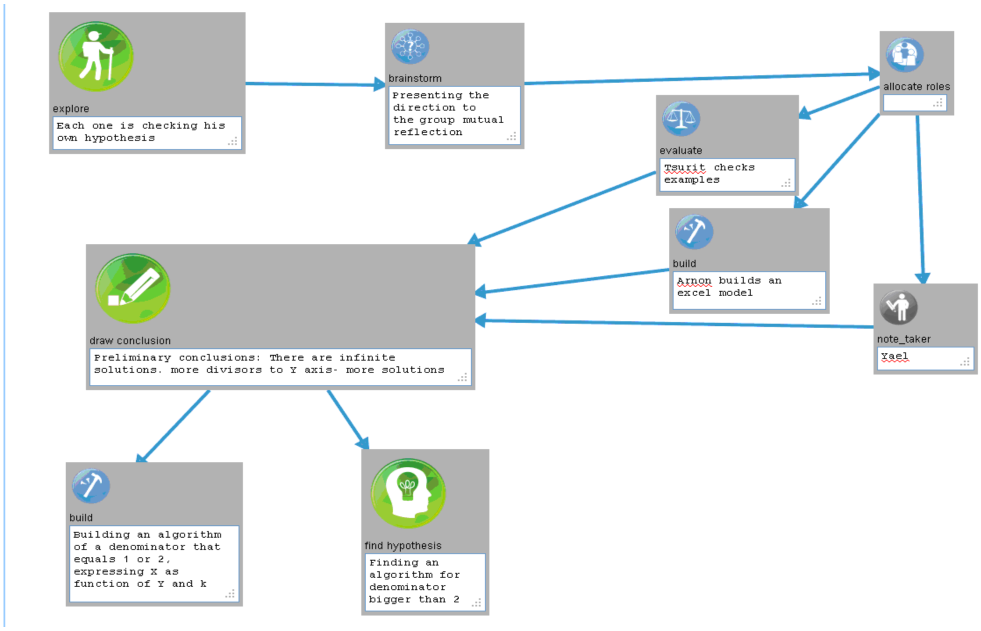


Figure 2 The plan progressively constructed by a group of four teachers

At first, each participant explored the challenge on his own, trying to figure out a possible solution. In order to do so they needed to come to shared understanding. For that matter the teachers co-constructed a mutual figure that serves as a model of a garden (Figure 3). In addition they came to mutual understanding about a formula that represents the relationships between three dimensions of the problem: X, Y and n (Figure 3).

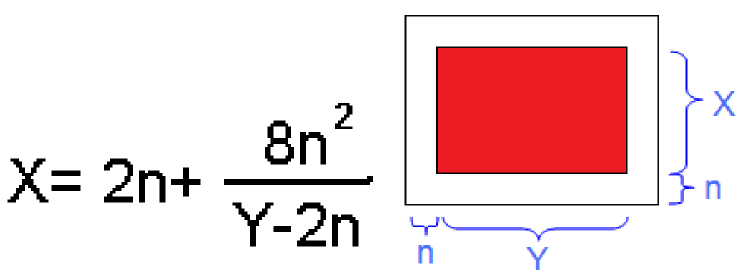


Figure 3 A model of the problem that was created by the solvers, a proper notation and an equation that connects between the three variables.

Then, they gathered around one of the computers for brainstorming. They used the planning tool to describe what they did so far, so that the planning tool served at this point as a reflecting tool to monitor own actions rather than as a planning tool. Still, the teachers needed to agree on the exact task that they carried together. While doing so we observed two different uses of the cards in the planning-reflecting tool. Yael conveyed a bottom-up approach, as she browsed through the visual symbols list in order to find representations of what she and her colleagues did. For her, the cards served as elicitors for describing the work. Arnon presented a top down approach. His approach was more reflective and abstract, as he first verbalized what the group did, and then tried to find cards that meet with his understanding of what the team did.

The teachers then allocated roles between themselves, and the group split to three parallel venues, based on the three-variables equation (Figure 3): Arnon went to another computer in order to use Excel for building a model for possible solutions. Tsurit decided to work with paper and pencil to create several examples in order to evaluate types and numbers of solutions. Yael – was given the role of a note taker. From that point onward, the planning tool was used by Yael according to Arnon and Tsurit's work. In return, Arnon and Tsurit consulted the on-going plan to decide on further steps. It appeared, from the video of their work that in this stage Yael had difficulties in building the on-going plan. As a result, she received assistance from the teacher in charge of the workshop, in organizing their plan.

Following this individual work, the three teachers gathered in order to draw conclusions from Arnon's Excel patterns and from Tsurit paper and pencil explorations. Arnon created a set of tables for the three variables equation, on one spreadsheet. From this equation, the three teachers reached the conclusion that the number of solutions is infinite. They then focused on their common planning-reflecting map and planned two directions (See figure 2): 1) Building an algorithm to find the values of X, Y and n when the denominator of the formula Y – 2n equals 1 or 2 (then X, Y and n are integers); 2) Finding a hypothesis about other solutions when the denominator Y-2n is bigger than 2. This was the end of their work, since time was up.

The workshop brought several insights, that could serve us in promoting our future work: (1) Elaborating an on-going plan is a demanding task, since (a) students and teachers are hardly familiar with this practice, (b) it requires making a pauses in problem solving, and (c) it capitalizes on the demanding tasks of self-monitoring and self-regulating processes; (2) The planning tool serves first of all to monitor past actions, and this monitoring helps planning further steps in the on-going plan; (3) In spite of all these shortcomings it seems that the planning tool may support the solution of challenges, and more importantly, the learning of collaboration strategies in solving mathematical problems.

Accordingly, we designed a course to foster collaborative problem solving. Next, we show the principles on which the course was based, and how we prepared the implementation of this particular *gardener* scenario.

The Course for fostering collaborative problem solving in Grade 8 students

One of the teachers of the workshop, Tsurit, an experienced teacher in mathematics, decided to organize a course in mathematical problem solving that reaches its end by the time of the writing of the current lines. Sixteen excellent 8th Grade students met once a week in a 90 min. long session in the computer lab, for eight months. We designed a series of activities to acculturate students to problem solving in small groups. To foster the acculturation to problem solving and collaboration, we (1) we chose problems that encouraged the elaboration of multiple solutions; (2) Like the gardener challenge, some of the problems were open-end challenges, thus affording the elaboration and the application of strategies to solve the challenge (Wee & Looi, 2009); (3) created collaborative situations to trigger productive interactions among groups of students (Dillenbourg, 1999).

The solutions of the challenges differed in their duration from 45 minutes problem solving to 3 weeks challenge collaborative solving. The scenario of the challenge was quite stable:

1. At the beginning of the lesson the teacher presents a challenge to the students, often in a general undetermined way to lead students to see and circumscribe the problem.
2. Groups of students initiate their autonomous work through preliminary explorations. They sometimes use the planning/reflection tool right away to figure out how they envisage solving the challenge. For very challenging tasks, students adopt an approach similar to that of the teachers: Individual work in order to construct preliminary understanding of the challenge, then join forces and reflect upon what they did and plan further solution process.
3. The students solve the challenge; they often turn back to their plan to reflect upon their solution. The teacher passes between the groups, in the class, and supports the different solutions paths. The Metafora maps of the groups serve the teacher to trace mathematical problem solving moves and to propose help.
4. At the end of the process the group recapitulate the work done and reflect upon it. In most cases, when time allows, several groups present their solution processes and their reflections to their classmates.

Sequence of activities: In the background of the course, a design research approach (Cobb et. al., 2004; Mor, 2011) was adopted, according to which the learning environment was assessed and refined and the design of activities became more precise. The course lasted 8 months. It included three main phases:

1. Warming-up activities to instil norms of collaboration in small groups
2. Enculturation to collaborative problem-solving: learning of specific heuristics and strategies; familiarization with the Planning/reflection tool, Geogebra & micro-worlds.
3. Solving challenges with increasing complexity

The course focuses on the following heuristics and strategies: Planning, Reflecting, "Thinking outside the box", abduction (backward strategies), introducing proper notations, Creating a model, Allocating tasks, Generalizing, Checking a simpler case, Hypothesizing, Checking hypotheses, Trial and error, looking for patterns, etc. In addition to the course, we elaborated a preliminary and a closing phase during which students solve problems individually and in groups, to assess development of heuristics and learning strategies in individuals and groups.

It appears that a crucial step for the success of this course was the involvement of the teacher in the design of the challenges. In the following section we will sketch how Tsurit designed with us “the Gardener” challenge, for this particular class. In particular, we undertook an epistemological analysis – meaning that we envisaged possible (complete, partial or flawed) solution paths to be capitalized on during class work.

The design of the Gardener challenge in the framework of Metafora

The teacher needs to be highly prepared for the support of a reflective, computer based, collaborative problem solution processes in multiple parallel groups. Tsurit's challenges were three, then. First, she needed to be familiar with reasonable solution paths with possible milestones, in order to be able to recognize particular solution process (partly through their Metafora maps). Second she needed to come up with an appropriate support that the team might need, in both group and mathematical levels. Third, she needed to be familiar with possible software and environments that might support the solutions.

We will now illustrate two envisaged solution paths that involve two computerized tools, Excel and Geogebra. We start with Tsurit's envisaged presentation of the challenge. Then we will bring an envisioned beginning of the solution by the students. Then we will describe the two possible paths to the solution, based on the solution of the teachers that is described above and solutions of the members of our team. In addition, we will list support she might need to provide.

Tsurit will start the following collaborative script, after the presentation of the problem:

> You have two weeks from now to work on the challenge I will present to you. Within two weeks, each team will present its solution, and will describe the solution process with the help of the planning-reflecting tool. Each team will have 15 minutes for the presentation. I suggest that at first, each one will sit with himself and think about the challenge. After you will gain some sense of the problem, log in to Metafora and plan how you are going to solve the problem. You may use paper and pencil, or any computer simulation you want that might support your work.

Tsurit will then present the challenge. She will then instigate an activity to *Understand the problem*. She will encourage as many questions as possible questions regarding the boundaries of the challenge. She will ask students to first discuss what the challenge is about: “Is there one solution?”, “Should we find all solutions?”, “Can the rectangle be a square?” No figure will be provided, and the *Drawing of a sketch* by all groups is likely to provide opportunities to understand the problem. The students are familiar with Geogebra, and may use it, or simply use paper and pencil. We envisage that Tsurit will ask one or two groups of students, after a while, to present the challenge and to explain why this is a challenge. We foresee that the groups she will invite will present a sketch and will report that they found several solutions but that they do not know whether they have them all.After this introductory phase, Tsurit will invite students to solve the challenge. We present here two planning/reflection maps that represent two possible solution paths of two imaginary teams.

The first map (Figure 4) is constructed by two students: Misha and Martin. First they follow Tsurit’s preliminary scenario, as both of them (1) engage in understanding the problem, and (2) create the sketch of the problem similar to the sketch in Figure 3. Then, they (3) engage in a discussion in which each of them presents his path for the solution. They (4) come up with agreed notations for the sketch, in order to "speak in the same language" (A sketch in which all variables are mentioned like in Figure 3). We envision that at this stage, Tsurit will offer them to reflect upon their solution so far, and to create a plan onward of their further common work. The students then come up with the explanation of their solution process (Cards 1 to 4) and then plan ahead (cards 5-7). First they (5) allocate tasks. (6) Misha uses Excel in order to come up with possible solutions; the way to achieve this goal is unknown. (7) Martin plans to build a mathematical equation. They both leave the planning tool to come up with solutions. Martin's attempts are successful as he provides an equation X = 2n (Y+2n)/(Y-2n) that connects between the three variables agreed upon. Martin immediately reports on the equation he found with the planning/reflection tool. Misha's first attempts with Excel yield one isolated solution (e.g., X = 6, Y= 4, n = 1). Based on a prompt by Tsurit, Martin is asked to share his knowledge with Misha.

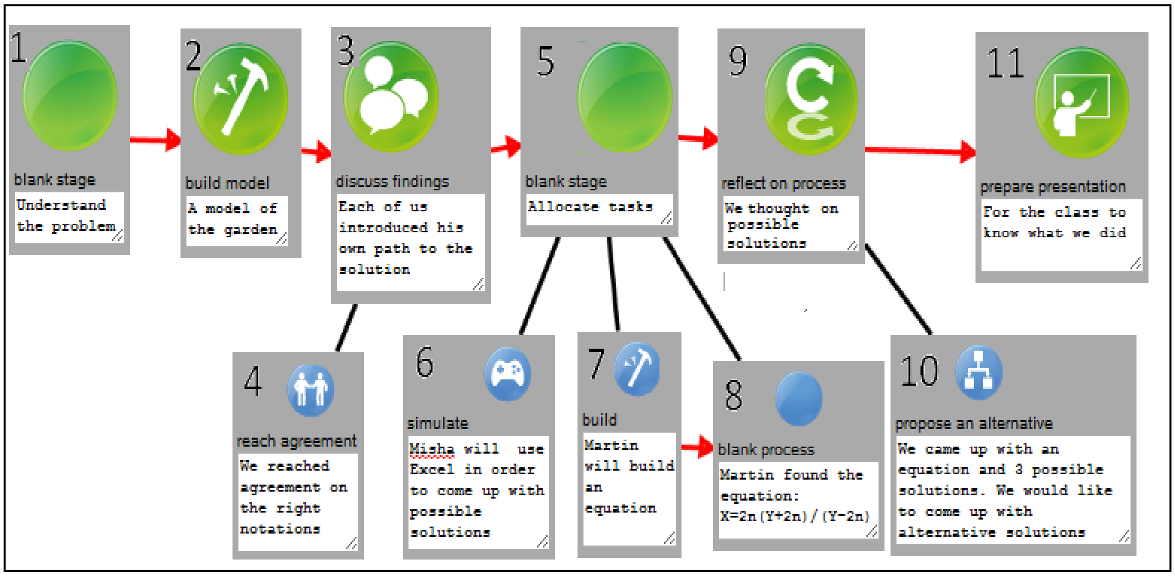


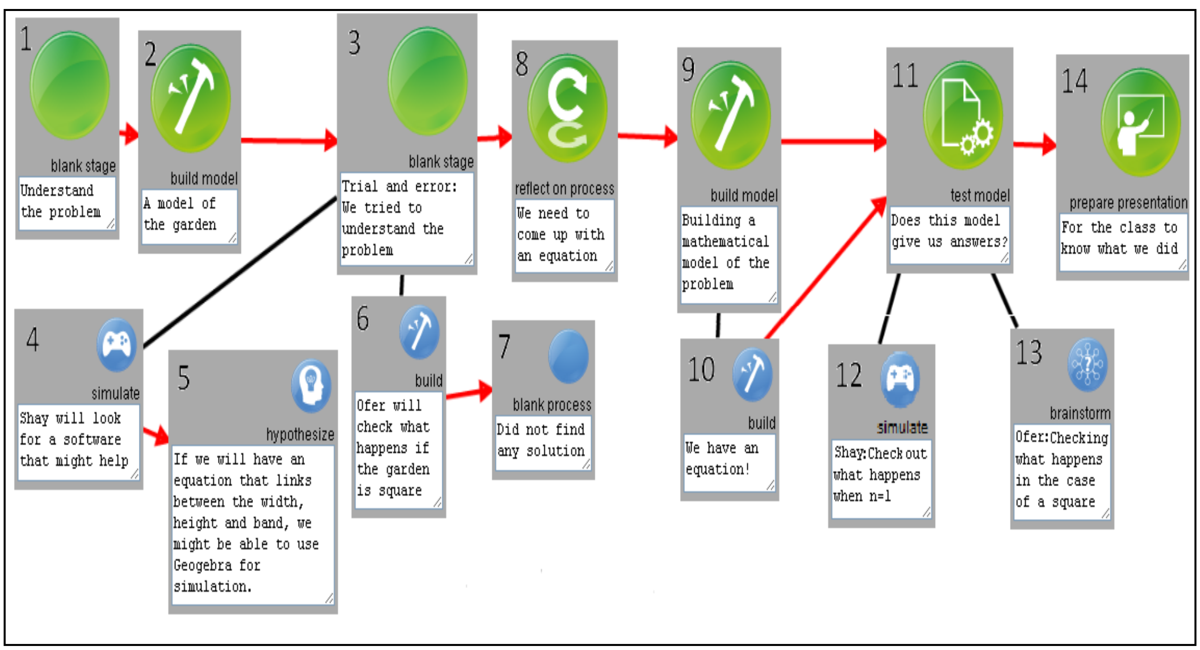
Figure 4: First example of a planning/reflecting map

Martin approaches Misha and shows him the equation and convinces him that Excel will give isolated solutions only. They abandon Excel and (9) try together to find solutions to the equation. At this stage, Tsurit reminds them that the solutions should be natural numbers. The team finds three solutions for the challenge by using trial and error attempts with eth equation, and goes to the planning/reflecting tool to report about it. While doing so, Tsurit asks them if they can generalize their solution. The team then goes back to the map and reports that they would like to (10) come up with alternative solutions. They keep on trying to generalize their ideas, but reach a dead-end. At this point they go back to the map, explain that their next step would be to (11) present their solution to the class.

The second map (Figure 5) is constructed by two other imaginary students, Ofer and Shay. Like Misha and Martin they go through the first two steps (1, 2). They first adopt a trial and error strategy (3). They are then prompted by Tsurit to reflect upon their work and to devise a plan of their future work. They put cards (1-3) on the map. They now decide to adopt more systematic steps in their trial and error attempts. (4) Shay assigns himself to look for software that might help them. After a short discussion they realize that Geogebra might help them. They come up with an hypothesis (5), according to which if they will find an equation that links between variables, they might be able to display its graph with a grid of natural numbers with Geogebra. Ofer (6) decides to check the simpler case of a square garden. After some on paper computations, he does not manage to find any solution. The team then goes back to the map and report about the unsuccessful trials. They are now stuck. The students (8) reflect upon their work and report that they need to come up with an equation that will link the variables of the model. They (9) create a mathematical model of the problem, based on support that is given to them by Tsurit, similar to the one that was given by the first team: X = 2n (Y+2n)/(Y-2n). When they have the equation, i.e. mathematical model, (11) they ask themselves, if their accomplishment will lead them to a solution. In order to do so they divide again, as (12) Shay start with a simpler case, checking what happens if n=1. For that matter he uses the dynamic geometry software Geogebra. We see in figure 6 an illustration in Geogebra for the function that applies for n=1. Shay finds out that the only integer solution in this graph is a 4X6 rectangle.

Figure 5: Second example of a planning/reflecting map

Ofer (13) goes back to his initial idea in which he verifies what happens when the shape is a square. He uses the mathematical model and places X as equal to Y. His computations lead him



to the following equation: $X=2n \pm n \cdot \sqrt{8}$. He observes this equation and realizes that if n is an integer, X cannot be an integer, and vica-versa. Last, the team members come up with a way to present their results, and solution process, to the class (14).

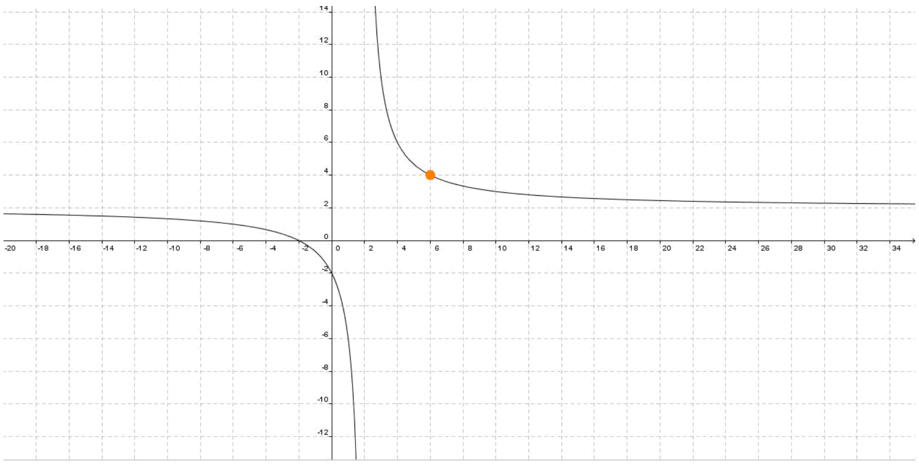


Figure 6: A Geogebra simulation for the function that applies with n=1 which is X=(Y+2)/(Y-2).

The final activity that takes place is the class Reflection in which the students will reflect upon their solution process in front of the class, presenting both their results and their solution process.

Conclusions

The solution paths presented here suggest that students will find some solutions but that they are far from having completed the solution of the challenge (in fact, it can be reduced to a Diophantine equation). As many times during the course, the partial successes of each team in their collaborative work and their difficulties in completing the task will prepare the ground for the teacher's modelling and scaffolding of more sophisticated heuristic moves. In our case, they will be probably mediated through a class reflection upon the various solution paths given by the teams, and the articulation of advanced moves (Checking the equation for X=Y or for n=1, using Geogebra or manipulating the relation $X = 2n * (Y + 2n)/(Y - 2n)$ to obtain $X = 2n + 8n^2/(Y - 2n)$ – leading to the generation of families of solutions by the method of exhaustion). These new moves are learnable because groups of students are now convinced of their necessity. Our paper has shown then that the learning of mathematical heuristics and strategies seems feasible in a CSCL context. We showed that the investment of the teacher in this endeavour is enormous but it seems worthwhile.

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Appendix 1: Possible support that might be given by the teacher

Group learning support:

1. What are you doing?
2. Why are you doing this?
3. How success in this direction could lead you to solve the problem?
4. Are you working according to your plan?
5. Do you want to revise your plan to show what you are doing?
6. Consider comparing your separate work.
7. Have you started working on your activity?
8. Consider asking for help from others.
9. Is this time to revise your plan?
10. Don't forget to reflect on your plan.
11. Does everybody know what he does?

Math challenge support:

1. Does everybody understand the challenge?
2. I suggest that you will draw a sketch of the problem
3. Are you all using the same notation?
4. What is the role of integer numbers in the solution?
5. Do you have a mathematical model?
6. Will modifying the mathematical model help you in this case?
7. You should explore patterns of solutions
8. What other patterns can you find here?
9. You can check the solution for n=1, 2, 3
10. Did you try any computer simulation that might help?
11. What other solutions can you find for this problem?

Drama in Education and Constructionism

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Abstract

This paper examines the similarities of two innovative pedagogies, Drama in Education (DIE) and Constructionism. It will be highlighted by theory and research that although they use very different means to achieve their goals, they both have a common objective, which is a more profound education where learning is achieved by 'making'. They both value the context in which learning is taking place and the artifacts with which learners engage in conversation. The description of a drama/theatre based learning experience will show how process drama and the creation of a theatre performance resemble with Papert's computer projects and 'constructions'.

Keywords:

drama in education, arts, constructionism, education, play

Introduction

The question is about how scientists and educators intend to best educate young people for the future. Ackermann (2001) wonders "who are we to tell the children of others what they should learn and how?" And continues arguing that no one knows what is best for the others.

However, historically, many educational systems throughout history were designed to support authoritarian and male dominant social structures. It was the kind of education that was "appropriate for autocratic kingdoms, empires and feudal fiefdoms that were constantly at war" (Eisler, 2000). Teaching methods were used to prepare young people to obey those who had the power. The same philosophy, also, underlay the traditional industrial model, which prepared workers by providing segments of knowledge, so they could find their place in the system and its hierarchies without questioning either (McCammon, 2002). Such models that do not invest in conscious, independent citizens who have their own sense of control, are not compatible with the emerging educational needs in our multicultural societies and are not viable anymore.

Additionally, for years a false polarity has dominated the education of the Western world to a great extent. Since the 17th century, the positivist, scientific way of research and knowing has excluded feeling from the sphere of true, genuine knowledge and has focused on the cognitive, intellectual modes of perceiving the world. This prejudice about the superiority of cognition had a disastrous effect on education. The affective domain was rejected, an alternative way of approaching experience, the intuitive approach, was disregarded and students lost opportunities to have deep, profound, dynamic experiences of knowledge through another channel, that of 'cognitive feeling', felt intuition and felt understanding (Reid, 1976). This led to fractured meanings and to students' limited and partial intellectual explorations and, as a result, education was deprived of a whole world of values and quality.

The two approaches described above inevitably drove educators to design programmed curricula with a pre-determined 'body of knowledge' where students were recipients, treated as vessels to be filled. According to Paulo Freire (1972) this is 'the banking concept of education'. As a result, students are dependent on their teacher to learn pieces of knowledge, so knowledge remains the property of the teacher (O' Sullivan, 2003). Students are supposed to live in democratic societies, but the final aim of the political systems which regulate education and invade local school communities is for students to serve the power games of the people who rule the world. It is as if dark forces undermine our schools, our homes and our lives. Teachers too, instead of educating students and helping them to become independent and revolutionary, "recycle the packages that others have generated" (Taylor, 1996) and serve the educational policies of their governments and of the dominators of the world, often unintentionally. Moreover, given the competitive world which emphasises excellence and personal achievements, most forms of education are individualistic and social aspects of education are neglected.

The necessity of a new educational philosophy

Another important issue is that in the above described model, students' differing needs and different learning styles were not usually taken into account. Howard Gardner's theory of multiple intelligences suggests that there are eight different forms of intelligence which are equally important: linguistic, logical-mathematical, spatial, musical, kinaesthetic, interpersonal, intrapersonal and environmental (Gardner, 1999). Each of these intelligences means a preferred learning style for each student. According to Gardner (1983), we deprive students when we are interested only in linguistic and logical – mathematical intelligence, and as educators we deprive ourselves of the possibility of building a whole child.

As a result of the above situation, some pessimistic people assume that young people only want to hang out and have fun, but this is not true. Young people crave experience and productivity. They want to try new things, to take inspiration from different sources and create new combinations of materials, ideas and people (Fiske, 2000). Thus, today's schools are expected to engage the whole personality and good education has to be rooted in a real life context. This pedagogical idea is known as holistic education (Vappula, 2004).

The fundamental ideas of the philosophy of holistic education are briefly explained below. Firstly, students come to school carrying with them their previous life, their experiences, attitudes, skills, knowledge, culture, needs and the characteristics of their personality. All these are important parts of a student's personality and cannot just be ignored, but have to form the basis of a child's education (Heathcote as cited in Vappula, 2004). Secondly, we are aware that the truth has many faces and students must be educated in a way that will enable them to see as many of these facets as they can. This process is very important in our post-modern society which is characterised by cultural variety and diversity. Thirdly, learning is not only a matter of what we know, but also a matter of what we are, how we feel and how we behave. According to Heathcote (as cited in Vappula, 2004), school must bring together three elements: the mind of people, the manner of being and the matter of doing, as we must live in the world of both the scientific right hand knowing and the mythical left hand.

Finally, Vygotsky's theory (1962), known as social constructivism, came to support another fundamental and necessary element of post-modern educational systems, the theory of cooperative learning. According to him, learning occurs because of the communication of the person with his/her social environment. Vygotskians believe in cooperation as a context in which peers inform, explain and intervene in a scaffolding way to attain new knowledge (Mercer, 1995 as cited in Matsgouras, 2004). The members of each team, working together, exceed their personal limits and this is Vygotsky's (1978) notion of the zone of proximal development. They take part in collective thought and actions, make the new knowledge familiar and individual and are gradually led to personal development and maturation.

In the light of the above theories education policy and curricula must be reformed in order to avoid separation of the brain hemispheres and the separation of people. The world must be seen as an inseparable whole, whose structural elements interrelate and interact in every possible way. At the same time, it must be seen as a field of multiplicities and in this way horizons will be broadened and new worlds will appear, ready to be questioned and explored (Greene, 1997). Maybe then, school would become a place of exploration, a place to share feelings and ideas, a community where educators, students and parents cooperate to ensure that each child will be respected and educated to live in more conscious, democratic and peaceful ways and to feel empowered to change the bad course of his/her life and the life of the world around him/her (Eisler, 2000).

Drama in education and constructionism: similarities

All the above theoretical foundation seems to underpin both Drama in Education and Papert's Constructionism. Both pedagogies imagine new environments for learning, put new pedagogical tools at the service of students and are interested in the dynamics of change. "They remind us that learning, especially today, is much less about acquiring information or submitting to other people's ideas or values, than it is about putting one's own words to the world, or finding one's own voice, and exchanging our ideas with others" (Ackermann, 2001).

Therefore, this paper is guided by theory and research that suggest that drama in education and constructionism as methodologies for learning share many common ideas. "The key terms of drama pedagogy (focus, framework, conventions, questioning technique, conciliation, dramatic forms of assessment, etc.) are the more peculiar representatives of the constructive character of drama" (Zalay, 2008). Such techniques help students to be open, discover their hidden features, structure their knowledge, build upon this knowledge and shape their 'own personal world'. Drama in education and the arts in general "can provide a rich and emotionally stimulating learning context in which students become personally engaged in their work through exploration, active involvement, and engagement of their particular activities" (Eisner, 2002). According to Heathcote (2008), the great DIE pioneer, in every society, there should be no greater priority than the need to reach young people and "create for them avenues for exploration". The ultimate aim for such a choice should be to empower young people to learn the 'old' knowledge and then to enable them to feel free to explore their own opinions in order to produce innovative designs, new applications of theory, 'new' knowledge and finally to make the transition to new beginnings.

Drama pedagogy can provide both teachers and students with the joy of creation. It is a conscious construction that considers alternatives and wishes to achieve concrete pedagogical objectives in the framework of a well-designed and continuously reflected structure. According to its intentions the participants can experience the experiential and situative learning process, that can develop or change their understanding of the world and as a result, practices of everyday life can be refracted and transformed. There is no brainwashing, no manipulation, no intimidation but playful and exploratory learning (Zalay, 2008).

Papert (1991), on the other hand, suggesting a 'catchy version' of the idea of constructionism thinks of it as a self –directed, active "learning by making" which means building knowledge structures in a context where the learner/student, in interaction with his/her world, is consciously engaged in hands-on explorations that construct a public entity. He is interested in how learners engage in a conversation with artifacts and "stresses the importance of tools, media and context in human development" (Ackermann, 2001). Constructionism, like drama and theatre in education emphasises creativity, discovery learning, building understanding and synthesis. Problem solving is also a fundamental idea for both practices, as using the categories of analysis and design, is closely related to creative thinking and involves producing a new response to a new situation, which is a novel outcome (Antonenko and Thompson, 2011). What is most important is that design activities for both educational approaches demand learners to be engaged cognitively, affectively and kinesthetically. The difference is that for the same purposes constructionists use tools like LEGO/Logo or Scratch to help students learn important mathematical and scientific ideas, while drama and theatre in education use dramatic and theatrical tools like narration, improvisation or rehearsal either to teach students school subjects or to make them socially or aesthetically/artistically literate.

Play

In addition, DIE and constructionism share another common element which is their penchant for playful learning. Henry Caldwell Cook, another of DIE's pioneers, placed emphasis on 'play', 'doing', 'being active' and 'following one's heart' in order to free his students (Bolton, 1998). The desire to link education and 'play' was fundamental to the development of drama and theatre in education. Peter Slade (1954) was the one who undertook the great challenge and managed to give 'play' in education professional status and propose it as the basis of Child Drama (1954).

Papert and Harel in the introduction of their book *Constructionism* (1991) also argue about the playful facet of their methodology. What is of great importance at this point seems to be the fact that, Papert was inspired to 'construct' constructionism from a soap-sculpture art class. He writes: "I want to be a person who puts math and art together". What he mostly liked was that the art students were dreaming, gazing, imagining, talking to other people, waiting and thinking, trying and dropping ideas before constructing a work of art. He wanted to unite fantasy, imagination and science in his own work, too. That's why he writes that "those who like to play with images of structures emerging from their own chaos, lifting themselves by their own bootstraps, are likely predisposed to constructionism" (Harel and Papert, 1991).

Imagination

Imagination is important to Papert's work. Citing a project at Hennigan School in Boston as an example, he highlights the fact that children trying to make a snake out of LEGO/Logo were constructing the content of their work through the free expression of their imaginations (Harel and Papert, 1991). Vygotsky (1998) argues that "everything that requires artistic transformation of reality, everything that is connected with interpretation and construction of something new, requires the indispensable participation of imagination" and again "imagination is a transforming, creative activity directed from the concrete toward a new concrete".

In using the arts, drama in education releases the imaginative capacity, breaks down barriers, opens up situations and frees people and leads them to see beyond what is termed normal or common sense. Developing the formal and aesthetic structures of their devised drama they create their own dramatic meanings. Thus, drama provides people with opportunities to discover new possibilities, new beginnings and new avenues for action (Greene, 1995; Doyle, 1993; Wagner, 1999).

Constructions and situated knowledge

The arts have always been a means of casting new light on the familiar, in order to see the world differently. Artists generally hold a mirror to society, but they do not simply represent and reflect reality. Instead, they restructure and reformulate conventional patterns, thereby uncovering the unrealised potential in society and establishing alternative visions (Doyle, 1993; Greene, 1997). Artists replace conformism with consciousness and reveal the inner needs of people.

Therefore, drama and theatre in education have their own potential as effective pedagogical tools. People develop through drama and students, by doing and creating drama, become part of a living-through experience, using their own resources to go beyond the predictable. This is a process of exploring the self, one's world, finding inner individual voices and also a process of emancipation (Doyle, 1993).

More specifically, taking into account that children learn better by making and doing (Neelands, 1984), drama and theatre create a safe framework for the students within which they can identify themselves with imagined roles, test reality, plan and reflect on several actions that resemble real life actions, handle situations, explore issues, events and relationships, imagine and create, become critical, make decisions, solve problems. In other words they can try out life itself. When using drama, logical and intuitive thinking are stimulated and knowledge is personalised while aesthetic pleasure is dominant. A dynamic unity of body, mind and emotion is used to achieve students' goals and this fact leads them to meaningful learning, to empowerment and to a sense of completion. Finally, given that drama and theatre are social forms of work, group and social skills are fostered in the participants.

A very special feature and a great attraction of both drama and theatre is that they are creative media that do not limit themselves in one form of expression or exploration. In this way, every student is encouraged to find his/her own style of learning, communication and interaction. In this sense, drama and theatre in education can play a vital role in promoting democracy, especially in post-modern multicultural and multilingual societies.

All of the above remind us of many ideas underpinning constructionism. Papert (1991) proclaims "vivent les differences" and argues that people prefer to think in their own way rather than in the 'best' way. According to him, his interest in differences and different intellectual and learning styles "set the stage for the evolution of constructionism". Papert's "bricolage" is almost the same as a devised theatre performance. Both are intellectual adventures of knowing and creating. In both cases students cannot stay with a pre-established plan. Both theories promote different ways of thinking and doing things and of constructing and giving form to their ideas. The result is always a personalised construction.

This view about individual people's ways of knowing and relating is also behind Papert's view of situated knowledge. Situated knowledge or learning is similar to living-through drama experiences. It means that certain knowledge cannot be detached from specific situations or context. In other words, cognition is grounded, experience- based and subjective (Ackermann, 2001).

Feminist approach

Finally, both DIE and constructionism value the feminist approach in education. According to feminist scholars "many women [and/or scientists] prefer working with more personal, less detached knowledge and do so very successfully. It this is true, they should prefer the more concrete forms of knowledge favored by constructionism to the propositional forms of knowledge [favored by traditional epistemology]" (Harel and Papert, 1991). Papert puts empathy at the service of intelligence and his 'child' "remains in touch with situations for the very sake of feeling at one with them" (Ackermann, 2001).

The arts and DIE, in particular, are considered to be an especially powerful setting for the emotional development of young people. Researchers have found that in art, the affective dimensions interact with cognitive dimensions and influence the quality of learning and life (AEP, 2004). Some neuroscientists and educators contend that learning cannot even occur without the presence of emotions and that emotional connections are necessary for memory, reasoning and deep understanding (LeDoux, 1996). In drama experiences, greater feelings and sensations unknown to the students are explored, "qualities and emotions that leapt the centuries" are touched, aesthetic satisfactions are felt and, in this way, the construction of personal meaning is facilitated (McCarty et al., 2004). Indeed, the discussion here is not about the direct pursuit of pleasure, in a utilitarian way, but rather about what Csikszentmihalyi (1997, as cited in McCarthy et al., 2004) calls emotional stimulation of creativity.

Concluding, DIE can unite the scientific and mythical levels of life, engage the whole human being, offer factual knowledge and also stimulate human interest and mystery (Vappula, 2004). Thus, a balance can be maintained between closeness and separation, openness and closure, mobility and stability, continuity and diversity, change and invariance (Ackermann, 2001). Through this lens DIE and constructionism complement each other and share similar goals.

A drama/theatre based learning experience

I will describe below a drama/theatre based learning experience, which was integrated into the school timetable, with 14 adolescents aged between16-18 years old, for one school year, in a Senior High School (Lyceum) in Palaio Faliro in Athens. The actual project and the research findings will provide evidence to support the idea that DIE is congruent with constructionism.

Methodology

This project was guided by the belief that the arts, especially dramatic arts, can play an exceptional role in the holistic development of young people and can offer them a high quality level of enjoyment and affect their quality of life.

The research was conducted in the light of changing methodologies and patterns of research in education and the humanities, which consider the two dominant approaches, quantitative and qualitative, complementary. The paradigm of critical educational research is also taken into account, in the sense that the purpose of this research "is not merely to understand situations and phenomena but to change them" (Cohen, Manion and Morrison, 2000).

Action research appeared to be the most suitable research methodology for the current project as drama and theatre in education is a newly introduced field in the Greek secondary school and the students are not only unused to this methodology, but also unused to the pedagogical philosophy that underlies it.

Three data collection methods were used: both structured and semi-structured questionnaires, semi-structured interviews, before and after the intervention, and participant, unstructured, overt, on-going observation. Moreover, materials produced throughout the project were used as data resources in the final analysis.

Research design

The arts' based experience involved a mixture of drama/theatre activities and games, process drama, theatre attendance, theatre rehearsals and theatre production. In the first phase, the students were engaged in two sessions of warm up drama/theatre games and exercises aimed at creating a comfortable atmosphere to help them relax, begin developing communication skills and build trust within the group. Some of these games also focused on developing initial skills in drama and theatre.

In the second phase, the work focused on process drama and several drama activities. The methodology that was used for planning the drama was mainly based on the dramatic conventions and techniques of Jonothan Neelands (1984), Dorothy Heathcote (Wagner, 1999), and based on work done on the structural elements of dramatic art by John O'Toole (1992) and Cecily O'Neill (1995). The pre-text was that the students were citizens of the year 2208 and had to take a trip to the past, as they were not satisfied with their lives. They chose artists as their common imaginative role (Wagner, 1999) and journeyed into different periods of time in the past aiming to find what was missing from their lives. Within this context, the students were asked to work on many scenes and characters from two theatrical plays: Shakespeare's *Mid-Summer Night's Dream* (2000) and Lorca's *Blood Wedding* (2002), without having read the plays. The techniques of improvised drama and devised theatre were also used. Through the process the students developed a lot of improvisations and enactments based on their own ideas. Demands which were made on the students were physical, emotional, spiritual and mental. This phase also consisted of reflection on action either in the form of conversations out of role or writing or drawing.

The same research process was followed in the third phase of the work, which consisted of preparation for a theatre performance and its attendant rehearsals. The students worked on all aspects of the production: scenery, costumes, sets and props, make up, coiffure, sound, lighting and publicity. The rehearsal process was enriched with more drama activities to stimulate creativity and to hold their interest (Wooland, 1993), to present an alternative approach to putting on a play and, last but not least, to reinforce the educational and aesthetic character of the experience as the aim was not to produce a professional performance but for the students to have a quality arts' experience.

Research findings

The participants in this study were invited to participate in the arts, to decode works of art and to respond and react to them in their own way. All the students stated that this experience was something completely new for them and that they came out of it with many new understandings and insights of themselves, of the world and their perception of it and of the existing relationships. Constantina said the whole work was very much more than a simple performance: "…we discovered and expressed our best self…", and Olga said that it was even more than a journey and its destination. Christina continues her thought saying: "It was a deep experience. We did not stay on the surface, we understood things…And then we did the performance to express something, not to just do a performance".

It was observed by both the teacher/researcher and the critical friend that focused perception, internalisation, interpretation, building insight, discernment, understanding consequences, abstract and concrete thought, fluency, originality, problem solving, and the ability to make decisions were some of the skills that were developed during the process. Students were very perceptive, penetrating, discriminating, discerning and analytical when creating their own scenes or stories and when reflecting and commenting on them. They had created scenes and perceived the characters, before formally meeting them in the plays, in unique ways that young people have of perceiving the world. In this way, they were given the chance to search deep into their own personal resources, to find and use their personal knowledge and existing experience in the process, to develop their own ideas and to become active meaning makers and creators (Neelands, 1984). They had a deep experience by drawing into experiences where knowledge is embedded rather than explicitly stated.

This process made them very excited, as they had discovered a way to give value to their previous personal experiences by transforming them into a significant arts product. This sense of ownership was unique for them. Other examples can be found at the moments when they started taking initiatives in every aspect of the drama and theatre work (their roles, music, costumes, make up, props and sets, scenery, publicity etc.), developing their own ideas, and expressing themselves with every means. They took several risks and finally created their own performance where almost everything that was presented was their choice. As a result, they considered it to be something that belonged to them and they carried through this work firstly for themselves and then for everyone else.

Expanding their imagination was another important result of the project. Christina noticed in her reports: "…using only our imagination we created an entire performance. Think what else we can do with it". The students experimenting to incarnate their characters tried at their own initiative, plenty of body stances, movements, gestures, facial expressions and tones of voice in order to provoke the laughter of their audience.

Moreover, the drama and theatre based experience under discussion offered plenty of opportunities to the participants to develop their inter-personal skills and to discover or construct aspects of their personal identity in order to make successful transitions to adulthood. All the students referred to the impact of the programme on the personal domain. Sophie was the student who stressed more than anyone else in her final questionnaire that the experience helped her acquire personal growth. She talked about building insights, personal development and expression in new ways. Building a sense of responsibility to the group and the project, setting and meeting goals, sharing a sense of common purpose and finally making friends were some of the results of the team work referred to by the participants and their parents. Improvisations where students came closer and co-acted, and discussions where they clarified their different aspects of reality assisted in the creation of a particular group's dynamics, where differences tended to be smoothed out by changing the balance of the group and its social health. Arts based experiences can also encourage students to search for alternative perspectives and to respect differing points of view, thereby teaching them to extend, to renew and to "hear more on normally unheard frequencies" (Greene, 1995).

All the students in the sample referred to the emotional stimulation and meaning which was provided to them by the arts experience they engaged with. They testified that they explored their own feelings and those of other people, either their co-participants' or their roles' feelings and that offered them personal insight. Some students noted that their relationship to the arts became more positive because they realised that the arts provoke a lot of emotions and free the person to explore and express them.

In conclusion, through the process of the drama and theatre based experience, the students developed an ability for creating art, acquired several technical/artistic skills in the arts and the art form, learnt to select, shape and organise material for performance, to compose imaginative works and to handle small details in artistic works that make the difference. As a result, they were empowered as art creators.

Conclusion

The above findings highlight the strengths of the programme because as Slade (1954) puts it, the aim of drama and theatre in education is "a happy and balanced individual". The participants in this study did not get stuck on their acting skills and roles and on the production of the performance. They enjoyed themselves, achieved the fullness of their personality developed and cherished a remarkable experience in the realms of education.

These findings, also, are congruent with the relevant literature and research in constructionism (Ackermann, 2001; Harel and Papert, 1991; Antonenko and Thompson, 2011) and support the idea that the two educational practices share the same vision. An educational system which can offer deeper meaning to young people, opportunities to be engaged in situations and through this process achieve moments of inspired creation and personal construction of knowledge. Perhaps the co-operation of the two pedagogies is an important challenge facing educational research and reform today.

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Learning how to learn with microworlds: feedback evaluation and help seeking

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Abstract

We report on on-going research about students' learning how to learn with microworlds. We argue that a study of metacognitive skills should take into account microworld characteristics and especially the way learners interact with microworlds. Our analysis focuses on an important phase during learner-microworld interaction; evaluation upon which subsequent actions and meaning generation is built. Research results revealed six different evaluation types one of which –impasse acknowledgement-was further investigated in the context of help seeking.

Keywords

Feedback, Learning to learn, transformation tools, help seeking, evaluation,

Introduction

Papert used the term "mathetics" to refer to the process of learning how to learn in constructionist environments: *I have defined mathetics as being to learning as heuristics is to problem solving. Principles of mathetics are ideas that illuminate and facilitate the process of learning* (Papert, 1980, p. 120). Although Papert's two mathetic principles – relate the new with something familiar and develop ownership over the new by constructing something with it (ibid) – have guided the design of constructionist environments, few studies in the area of constructionism have stressed this element in learning as most studies in the area focus on the learning of the subject matter (i.e. maths, science, programming etc). Metacognitive awareness in constructionist environments has been described to involve problem finding skills, cognitive flexibility, continual evaluation and monitoring the solution process, controlling destructions and anxiety, becoming aware and activating problem solving strategies (Harel & Papert, 1991a).

In this paper we report research on elements of 'learning how to learn' process with constructionist environments. We focus especially on the evaluation process which is related to the feedback generated by the microworld. We see feedback interpretation as a complex learning process that involves not only learning of the subject matter but also reflection, monitoring and evaluation of the learning process (Schraw, 2007). Our research revisits metacognitive awareness in constructionist environments from the point of view of evaluation because, as we will show in the next section, it is an important part of the learner interaction with the microworld. The second part of our analysis discusses how students deal with situations which are evaluated by them as impasses. Impasses are crucial from a learning and meta-learning perspective. From the learning perspective, impasses can trigger the construction of new knowledge or they can prevent essential interaction with the microworld. From the meta-learning perspective, impasses entail handling frustration, seeking new resources, reflecting on previous actions, evaluation and integration of the suggested solutions. In the following sections we describe how evaluation is related to microworld characteristics and we discuss help seeking as a context for handling impasses.

Microworlds as transformation tools: transforming user actions into microworld behaviour

In order to describe the characteristics of microworld feedback we will borrow from Verillon & Rabardel, (1995) the concept of transformation because it is related not only to tool use but also to learning. Specifically, with respect to tool use, transformation has a dual role a) individuals use the tools to transform the environment (ibid) and b) individuals make sense of the tools through the interpretation of the causal relationship between the user actions and the transformations of the environment. When it comes to learning, tool-use is associated with transformations of the task/object of the user/learner (i.e. instrumentation Verillon & Rabardel, (1995)) and of the relationship of the learner to the knowledge integrated/represented in the tool (Mariotti, 2002).

Microworlds come with a transformation mechanism which changes user actions into a representation familiar to the learner (1st mathetic principle: associate the new with something familiar Papert 1980) compatible to the concept negotiated and usually completely different from the actual action performed. To further illustrate this we will use the familiar example of drawing a house with a roof in Logo. To draw a house the student has to type Logo commands in the editor. This action is projected on the microworld (i.e. the typed commands appear in the editor) but this is not where the story ends because this action is transformed within the microworld into a behaviour completely different from the initial action. Command typing leads to a sketch of the house appearing on the screen. Thus, in microworlds learner actions are processed in two ways: one is what we called "projection of user action" where learner's actions on the tool is rather analogous to what it appears on the tool (i.e. pressing the letters "fd" in the Logo editor results in having the letters "fd" appearing in the logo editor). The other is the transformation of action into microworld behaviour (*i.e. any change in the state of the microworld that is caused by user actions.*) according to "rules and laws" built in the specific microworld. Learning is intertwined with unlocking this transformation mechanism in order to find the causal–effect relationship between user actions and microworld behaviour. This idea draws upon the causality effect which is described as meaning making mechanism for tool use by Verillon & Rabardel, (1995). One way of depicting the process of learner interaction with the microworld is shown in fig. 1.

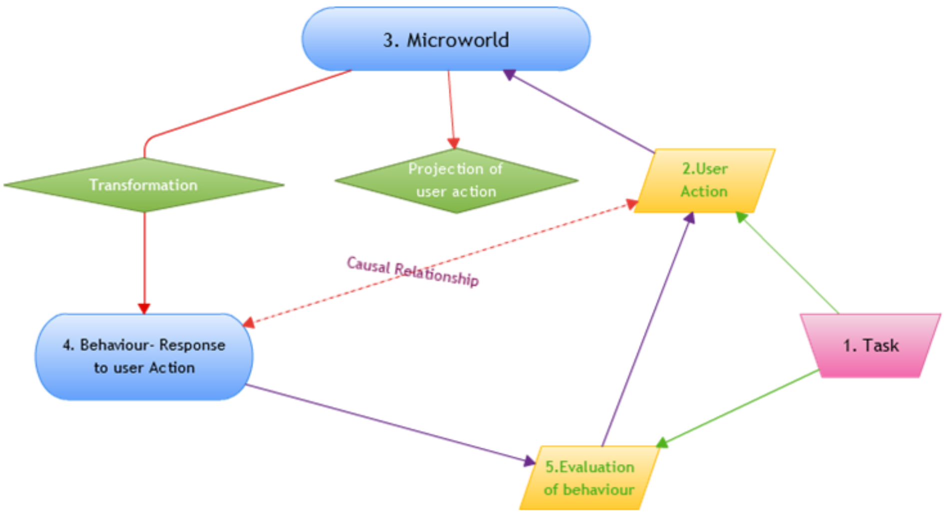

Figure 1. The loop of learner interaction with the microworld

According to the picture above, learner interaction with the microworld in traditional settings is structured around the following pattern:

- The learner performs an action in the microworld (point 2 in fig 1) which is based on a specific goal that they have either directly (e.g. provided by a given task) or indirectly (e.g. set during the problem solving process (point 1 in fig 1). Examples of goals and user action could be the following: adding a command in order to construct a house, changing the values of a variable or dragging a slider in order to change the value of a parameter and investigate its effect, etc
- This action is projected on the tool (point 3 in fig 1 e.g. the typed commands appear on the screen). In contrast to several tools (e.g. presentation tools or word or image processing) the loop of user interaction with the microworld does not end with the projection of the user action in the tool (e.g. the text typed). Evaluation, reflection and new task analysis is a prerequisite for subsequent interaction with the microworld.
- The transformation mechanism changes the user action into microworld behaviour: e.g. drawing a house with a roof that doesn't covers the house. The specific graphical output (or an explicit message from the microworld) is a behaviour generated by the microworld (point 4 in fig 1) as a response to the student's action (typing the commands that create the house) and thus provides feedback either directly or indirectly.
- In order for the students to know if their goal has been achieved they need to evaluate (point 5 in fig 1) the behaviour generated by the microworld (i.e. the house with the flawed roof) against the expected behaviour according to their goal (a house with a proper roof).

The results of this evaluation will either end the loop or will become the basis for the next user action (e.g. change the first turn of the turtle). Evaluation of microworld behaviour might also result to a new conceptualization of the task and lead to the formulation of new goals.

One important aspect of evaluation in this loop is that it is expected to be performed by the learner on a perceptual basis (Balacheff & Sutherland, 1994). But how can the learner evaluate something that he/she is learning and do not know already? In the case of microworlds the learner is expected to evaluate the impact of his/her actions on the microworld (i.e. the behaviour generated) based on the fact that the feedback is a representation of a concrete object or phenomenon which is familiar to the learner (i.e. the sketch of a house). Thus the learner evaluates the behaviour of the microworld against the expected results of his/her actions according to the task or to their goal. To further illustrate this let's use the example of the house construction: the learner might not know how much the turtle should turn in order for the roof to fit the house but as soon as the commands are executed the learner can evaluate if the graphical output looks like a house or not.

Evaluation of the behaviour might be followed by an interpretation of why things happened this way (that is an interpretation of the causal relationship between user actions and microworld behaviour) and of a reflection/evaluation on the user action. Reflection on user actions is usually indirect because it is based on the impact these actions are having on the microworld (i.e. which action on the microworld caused this behaviour). Evaluation is necessary for the next action the way a chess player takes into account his/her opponent's actions. It is in this sense that the evaluation of the microworld behaviour is a prerequisite for the next action on the microworld --- it shapes and directs the user interaction with the microworld. If such an evaluation will not take place then it is most likely that the learner will perform, at best, random actions on the microworld and may not complete the task. For this reason some microworlds scaffold evaluation providing explicit feedback for example through intelligent analysis of a certain task the student is undertaking drawing explicit attention to the lack of a goal achievement (see Mavrikis et al., to appear). Our analysis in the data section shows the focus of student evaluation of microworld behaviour and how students handle impasses during their interaction with the microworld. More often than not, evaluation might trigger the need for social interaction and particularly help-seeking on behalf of the learner or can be used as an opportunity for a justified intervention on behalf of a teacher. After summarising the characteristics of microworld feedback we elaborate on the social element of evaluation.

The characteristics of microworld feedback

We described above how the transformation mechanism in constructionist environments shapes the feedback generated by the microworld (microworld behaviour) as a response to user's action. This feedback has the following characteristics:

- It is another representation of the user action (consider for example the command "fd 5" typed in the Logo editor which is transformed in a representation of a line of specific length) which
    - is relevant to the concept under investigation
    - is usually a specific object or a phenomenon (Balacheff & Sutherland, 1994)
    - is familiar to the learner so that it allows perceptual control of the actions on the microworld (ibid). (The learner knows what a sketch of a house looks like – connecting the new with the familiar Papert 1980)
    - evolves along with the learning process (Balacheff & Sutherland, 1994) as this process is manifested through the learner actions
- It is an integral part of the microworld design and it is generated according to a "domain of phenomenology (ibid)" which in essence determines the translation mechanism, that is how user actions will be transformed into microworld behaviour and what kind of behaviour would this be ("phenomena at the surface of the screen" ibid). Thus, the domain of phenomenology actually determines which representation of user actions is best for supporting the negotiation of meanings with the specific microworld (consider here the idea of "body syntonicity" Papert 1980 dominant in the turtle graphics which leads into the drawing of shapes as the trace of a moving turtle – the case of circle here is indicative)
- It is not necessarily an evaluation of user action (as opposed to the feedback offered by drill and practice environments which explicitly evaluate response correctness) but could be implicit or explicit in drawing students' attention to the lack of goal achievement

Help seeking as a social dimension of feedback interpretation

We believe that a particularly interesting consequence of evaluation of microworld behaviour is that it can act as a trigger for social interaction and particularly help-seeking from peers or the teacher which in turn can play a pivotal role in how the feedback is interpreted and shape both the meaning and importance of subsequent user actions. Research in the area highlights the distinction between executive and instrumental help-seeking (Nelson-LeGall, 1985). Executive help-seeking involves seeking answers to problems directly. This may lead to task completion but does not facilitate deeper understanding. Instrumental help-seeking involves requesting help for demonstrating or explaining the method by which the problem can be solved, allowing the student to retain responsibility for the solution and to acquire new knowledge. This way the help seeker not only can remedy their immediate problem, but also ensure long-term autonomy. The type of help students seek and provide is influenced by implicit approaches to learning in general and therefore engaging and reflecting in help-seeking and giving is an important element of self-regulated learning (Nelson-Le Gall, 1987; Karabenick, 1988).

Tools and tasks

This study takes place in a learning environment mediated by the Metafora System – a platform which integrates microworlds with computer-supported collaborative learning (CSCL) tools (i.e. a planning tool and a discussion tool). Integration involves communication between elements of the different tools such as accessing microworlds through the planning tool, exporting instances of microworlds to the discussion tool etc (for a more detailed description see Mavrikis et al 2012 and other publications in http://www.metafora-project.org). In this study students used 2 out of the four microworlds integrated in the Metafora system and the discussion tool which is called LASAD. In the first phase of the study students used the 3d juggler microworld which consists of 3d objects (three balls and four bases) placed in 3d space. Students can control the motion of the balls changing the values of the motion variables (speed, wind direction, altitude, azimuth etc). The task in which students were engaged with the 3d juggler was to manipulate the motion of the balls so as to hit each other's base in a circular manner (i.e. the red ball should hit the blue ball's base, the blue ball should hit the green's base, and the green ball the red's base).

The second phase of the study involved the use of eXpresser microworld and LASAD discussion tool. eXpresser is a microworld for building animated models using figural patterns of tiles to support students' learning of mathematical generalisation. It also incorporates intelligent support; and tools that help teachers track students' progress. The task with which students were engaged involved the construction of a train track model in eXpresser using different coloured tiles to distinguish the different patterns that constitute it in the way they visualized it (see an example in fig 2 where the pattern is embedded in a discussion). Their final goal is to derive a rule based on the structure of their constructed train-track model that gives the total number of tiles for any model. Therefore the choice of patterns and structures is left to the students. Students during this phase were asked to use LASAD to ask for help from other students or their teacher. LASAD is a discussion tool where students can contribute remotely to the same discussion space and can also integrate in the discussion models they created in eXpresser (we use the term referable objects which is described in detail in Mavrikis et al 2012). Discussions in LASAD have the form of concept maps aiming to visualize the contribution types in the discussion (see figs 2 and 3)

Method

In our study we employed design based research (The Design Based Research Collective 2003) because a) it is grounded on theory and research results b) aims at studying interventions as opposed to other qualitative methods (Collins et al 2004) and c) informs theory and the design of the intervention. Our study is divided in two phases, the first phase was grounded on theory about metacognitive awareness and microworld feedback aiming to explore how students evaluate microworld behavior. This study took place in one of the Public Junior High Schools in Athens (2nd Experimental Junior High School). Four 13 year old students participated in the study and worked in groups of two with the Metafora Platform and specifically the 3d –juggler microworld for three and a half hours (in one session). The second phase of our study was grounded on the theory about learning to learn together and especially on help seeking as well as on results of the first phase of the study. The second phase took place in a school in UK, four 11 year old students and their teacher participated in the study which lasted five school hours (in 4 sessions). Students used the Metafora System and especially the eXpresser microworld and LASAD discussion tool.

Data Analysis

In this section we analyze a set of data that aim at casting light in two research questions a) what are the characteristics of learning how to learn with microworlds and b) how students handle situations which are evaluated as impasses in the process of interacting with the microworld.

Evaluation types of microworld behavior.

The first part of our analysis focuses on the evaluation phase of the learner interaction loop with the microworld. We consider evaluation as a crucial element of learner interaction with microworlds for the following reasons a) it directs learner actions with the microworld b) it requires the use of skills that are central to learning how to learn (planning, reflection, monitoring (Schraw, 2007)) and c) student problems in proceeding in meaning generation might be grounded on the evaluation phase where they fail to interpret the microworld feedback)

Our data collected during the first phase of the study with the 3d juggler mwd, were analyzed with respect a) to the user controlled elements of the student microworld interaction i.e. evaluation, user action, and b) to the microworld feedback and the task (see fig 1). Our analysis revealed six different types of evaluation:

i. **Personal**: This type of evaluation is directed towards the group member who performed or suggested the action It appears in cases where the microworld behaviour is either quite close to the result or quite opposite to it. So, it might be fine tuning of the previous action or might lead in a complete different action as in trial and error. Involves only microworld behaviour.

22: What are you DOING????
48: Don't be stupid
126: I am God!

ii. **Boolean**: Boolean evaluation focuses on the behaviour generated by the microworld and has the form of good -bad, right – wrong. Involves only microworld behaviour and occurs in contexts similar to the ones described in personal evaluation.

19 NO
50: Good! You see..
81: Oh! What is this??? Wait! Wait!
105: Nothing!
116 This is not what we want

iii. **Descriptive - problem focused**: When students use this type of evaluation they focus on describing the problem they encounter. The wording of the problem is formed upon the difference between the actual microworld behaviour and the result the students aim for. In this type of evaluation there is no explanation of why things happen this way

110: It goes up!
19: It hit the green base
50: Ahhh! It didn't even touch that one!
100: You see? It moves towards this base, that's the problem

iv. **Task-goal oriented evaluation:** In this type of evaluation students compare the microworld behavior against the task or the goal they have set (lines 61 and 62). Another variation might initiate the formulation of a new goal (change the turn instead of making the ball to hit the red base) for student actions or the analysis of the task into subtasks (Line 71):

63. S1: That was close!

64: S2: No, not really. This ball should go here (indicates that the red ball should hit the blue base) but this ball should stay here. Right?

71:S1:Wait! One step at a time. It has to turn more. Let's do that for now.

v. **Explanatory - Causal**: This type of evaluation offers an explanation that connects student actions with the generated microworld behaviour. Thus, students do not just identify what the problem is as in descriptive - problem focused type but they also attempt to interpret feedback and explain why the problem occurs or why things happen this way.

110 When we move this one [he points at one of the sliders], it goes up.
This one controls how high the ball will go.
115: This one is for the direction! Move that!

vi. Acknowledging an impasse: This evaluation involves again microworld behaviour but there is also a dimension related to the limitations of students' actions (I can't understand.... no matter what we do) and an evaluation on them: the strategies we tried doesn't give us any idea of how to proceed. This acknowledgement might interrupt the loop of the interaction with the microworld and at this point students might call for the teacher or stop for a while and try to come up with a completely different idea compared to the ones tried before.

73: I can't understand! No matter what we do, the ball moves straight
94: Same thing again! Straight line!

The data we presented in this section involved the evaluation of microworld behaviour. Our main observation was that only one of the six types of evaluation –the explanatory causal- involved a reflection on student actions which in turn were connected to the microworld behaviour. This evaluation type — which in essence is a conjecture about the mechanism that transforms student actions into microworld behaviour — seems to formulate the basis upon which students grounded the next action on the microworld. With Personal and Boolean evaluation types students express the results of the comparison between the actual microworld behaviour and the expected behaviour. These evaluation types are in a subtle way an evaluation of student actions in the sense that based on this evaluation students might repeat an action that seems close to what they expected or they might try out something completely different if the previous action led to an unexpected result (as in trial and error). These evaluations are different from the explanatory type in that they are less fine grained (yes/no type) and as such they do not offer an explanation on what is the problem and how things work or why happen this way. Descriptive, problem-focused evaluation is enriched with a description of what seems to be the problem which is expressed mainly in contrast to what the expected result was. With respect to learning how to learn, being able to identify the problem is the first step to resolve it. Task or goal-oriented evaluation compares microworld behaviour against the set task or goal or becomes the basis upon which a new goal is formulated. So it seems that this type of the evaluation can lead to a) revisiting – and even reconceptualising - the task and b) to breaking down the task into sub-tasks or goals both of which are important elements of learning how to learn. Finally, the last evaluation type is what we called acknowledgement of an impasse where microworld behaviour triggers an evaluation of student actions. From the point of view of learning how to learn this evaluation has to do with acknowledgement of the limitations of implemented strategies and with seeking new resources and ideas. The way students handle this situation varies: they might stop working for a while, they might get frustrated, they might check out what other students do ("floating of ideas" Harel & Papert, (1991b)) or they might call the teacher to help them out. Impasses are very crucial moments during interaction with microworlds because overcoming them might be grounded on construction of new knowledge and advancement of previous strategies. Next we describe an intervention aiming to record how students handle such impasses when they deal with them in the social practice of help seeking.

Handling impasses in the context of help seeking

In this section we discuss data from the second phase of our research where students worked in separately in the task of constructing train tracks with eXpresser. At the beginning of the task we introduced the idea of help seeking to the students telling them that if they felt that they needed help with their task in expresser they should describe their problem in the shared space of LASAD for other students and the teachers to see and offer their suggestions and comments. LASAD was chosen over face to face communication for two reasons a) exchanges on a problem encountered and discussed by one group become public entities that might be useful and enriched or modified by another group b) in LASAD discussions student constructions are integrated with the form of referable objects (see fig 2 and 3) and become part of the discussion –thus as the discussion unfolds different states of the construction are integrated in it c) LASAD offers the potential to structure discussion defining different types of contributions. For this study we used contributions such as “help request” for the students to describe the problem they were encountering and bring in the discussion the problematic construction state,” microworld actions such as change symbolic expression or find relationships”, “comments” and “my microworld” contributions where students could bring into the discussion a specific construction state.

Our data in this section are derived from student exchanges in LASAD. In the pictures below (fig 2 and 3) we depict two instances of help request with larger LASAD discussions. Figure 2 depicts an interaction between two students (S1 and S2) with an intervention from the teacher. The episode depicted in fig 3 takes place after another student S3 was prompted to check out the discussion between students S1 and S2 . After reading the discussion map in fig 2, and because of the lack of detail, S3 was not helped and instead posed a similar question, which the teacher decided to answer due to the lack of other students who could help at the time. Both S1 and S3 encounter the same problem: when the ‘play’ button is clicked the variables involved in two patterns change randomly and thus the construction looks ‘messed-up’. This problem can be solved by ‘linking’ the variables together using a symbolic expression to represent the relationship between them (Mavrikis et al. 2012). In both episodes students use the same “method to ask for help”: they combine the verbal description of the problem (in both cases a rough description of the microworld behavior: how to make both patterns move together) with constructions that either represent the problem (fig 2) or the expected result (fig. 3).

The main observation when comparing the two discussions is that student discussion is dominated by construction examples (fig 2) rather than the more expert-guided discussion that consists of requests for verbal descriptions of problems and solutions (fig 3). More specifically in the first episode help seeking and problem resolution had the following form: S1, described his problem, S2 opened the model, identified the problem and suggested a solution in the discussion (i.e. change the expression of green to repeat red -1) and provided a corrected model. S1 copied the solution suggested by S2 in his model and asked from S2 to provide further help on the next step (what is the rule that makes the model to work). In this discussion (despite the teacher’s request) there was no further elaboration on the problem and its solution and thus it could not offer any information about this problem to S3 later. In terms of help seeking, S1’s and S2’s behavior seems inherently executive (ie seeking or providing the solution to the problem) rather than instrumental (i.e. explaining the method to resolve the problem) (Nelson-LeGall, 1985).

Fig 2 Help request: student interaction

A completely different situation is observed in the second episode where the teacher aims at guiding S3 – rather than providing a solution – by suggesting that he first observes and expresses relationships. This helps S2 to resolve the problem. The question that we are posing, therefore, for further research is how we could structure the social interaction between the students so as to facilitate deeper understanding through the process of help providing and help seeking.

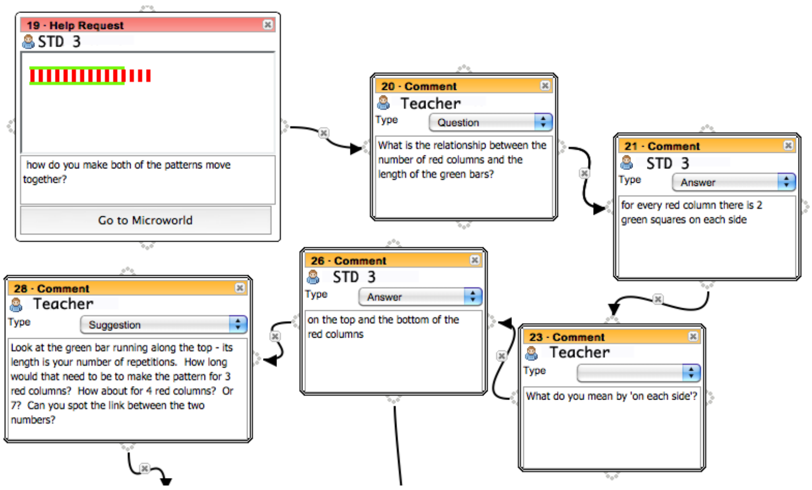

Fig 3 Help request: student – teacher interaction

Concluding Remarks and future research

Our analysis on students' learning how to learn with microworlds revealed that the evaluation process is a crucial element during learner interaction with the microworld and can take various forms linked to social aspects (personal evaluation) different understandings of the concepts under investigation (Boolean evaluation and explanatory – causal evaluation), and learning how to learn skills (i.e. describing the problem, identifying an impasse, reconceptualising or forming subtasks or goals). Thus our research contributed in elaborating on the different types of evaluation that might take place during interaction with a microworld and linked them to other elements of this interaction (task/goal and subsequent actions on the microworld). Our study further focused on situations which are evaluated by students as impasses and we analyzed how students handle these impasses in the social practice of help seeking. Research results showed that dealing with an impasse is a critical point, rich in learning opportunities which can lead to the construction of new knowledge. Students however, seem to have difficulties in articulating their problem in explaining the method for resolving the problem and in personalizing suggested solutions before integrating them in the constructions. Based on these results our future research will focus on designing an intervention which aims at structuring the help seeking process with a set of contributions in LASAD which are based on meta-cognitive skills (reflecting, setting goals and subtasks) and microworld actions (e.g. finding relationships, describing unexpected results).

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Designing Tools for Creative Learning

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Abstract

In this paper I present two tools for reflective, creative thinking: Pillow-Talk and Calliope; and discuss the research that led to their design. These tools make use of the "distorted mirror" metaphor for self-reflection. They are aimed at debunking myths of creativity as an acquired faculty promoting instead creative apperception and flexible thinking.

Their design parameters are built around the idea of making full use of the different vehicles and levels of thought accessible to us.

Pillow-Talk's targets flexibility in levels of thought by priming dream recall and facilitating capture through voice recording. It considers the dream an aesthetic experience we all undertake, where the dreamer is free to test knowledge liberated from physical and moral constraints.

Calliope endorses flexibility in vehicles of thought through co-creative and collaborative play. One can incorporate any object found in the environment as a tool or material, thus making contextualized and personalized creations. Calliope promotes cross-cultural and cross-generational co-creation as the echo from which to recenter perception.

Keywords

Technology, Creative Learning, Dreams, Constructivism, Constructionism, Reflection, Collaboration

Introduction

There is a general concern about the unpredictability of the future in a world that is changing faster than we can keep up with. In order to adapt, it appears that everyone, from education to entrepreneurship, is calling for more flexible, creative modes of thinking. Creativity is almost becoming a trend, being valued as highly as expertise as an asset to achieve "success."

Thinking creatively though, requires fluidity between abstract and concrete, internalizing and externalizing, combining new information with pre-acquired knowledge. Thinking creatively demands self-knowledge. (Ackermann, 2007)

But it seems like the same environment that demands flexibility of mind overlooks the need of time and space for creative thinking; and the crucial role that reflection plays in the equation. Information technologies have focused on access and distribution of media, their highlight being the capacity of personalization and exchange, but little attention has been paid to the creation of content itself. But when the environment does not demand creative engagement and instead asks for compliance, a sense of futility pervades. Our creative nature is overtaken by the one of consumers and transmitters.

Creative apperception is of crucial importance to psychological health. "It is only in being creative that the individual discovers the self." (Winnicott, 1971) Robert McKim states that we can only become integrated beings if we are able to transfer back and forth between rational and emotional, to plunge into the unconscious and bringing it up to conscious attention, in short, when we are able to have an ambidextrous mind. (McKim, 1972)

But how is one to exercise and maintain a truly creative apperception? How can we acknowledge ourselves as creative beings, appreciate the uniqueness of our vantage point and debunk myths of creative handicap?

Access to our mental process, the ability to step in and out from ourselves through perspective taking, endorsing the value of personal experience and providing a time and a space to reflect need to be considerations taken when designing tools for creative thinking. Technology should help us engage in an inner dialogue through which personal, original content can emerge.

In this paper I present tools to foster creative thinking: Pillow-Talk and Calliope.

Pillow-Talk is a tool to aid dream recall. Its aim, beyond exposing the dreamer to the wealth of their self generated visual imagery, is to promote flexible thinking by allowing access to both conscious and subconscious levels of thinking; bringing a renewed sense of ourselves as creative beings.

Calliope aims to promote the creation of personalized and contextualized work by allowing the use of objects as material for creation. Designed as networked platforms, Calliope hopes to foster a flexible mind that permits alternative viewpoints where people from all cultures and ages can come together to internalize through their externalizations, learn from and through their and each other's manifestations and exploit the creative potential their environment possesses. In short, a stage to be, share and reflect.

These tools were designed with mindful consideration of providing space and time for self-reflection. They explore how the artefact, whether a physical object or an object of thought, serves as a soundboard for our thought process.

Reflective Learning and Adaptation

Adaptation is understood as the balance between assimilation and accommodation, between incorporating new information into one’s preexisting cognitive structure and changing this structure to accommodate new information. (Piaget, 1954)

Given the speed at which all areas of our culture are changing, adaptation is a constant requirement. Information from the environment is becoming not only accessible but intrusive, reaching us at a speed never experienced and from channels never seen before. It seems as if our time to create and reflect has been compromised by the manufactured need to be present everywhere and with everyone all the time, depleting ourselves from a space and time for intimate interaction.

If adaptation is the product of equilibrium between assimilation and accommodation, it is fundamental for the individual to have a deep understanding of what constitutes him or her as an integral being. The creative act, creative apperception, obliges oneself to be, exposing rather than hiding our persona.

But creative enterprise seems to be easily mistaken with impulsive action. Creative thinking requires reflection and the postponement of immediate action. In John Dewey’s words: “There is no intellectual growth without some reconstitution, some remaking of impulses and desires in the form of which they first show themselves.” (Dewey, 1963)

Reflection then, is an integral element to learning.

Reflection happens when we synthesize experience into knowledge, when we take distance from what we know, when we take a different perspective and see through someone else's eyes. Reflection is influenced by how we feel as we reflect and happens as well when we share our thoughts and listen. Artefacts provide reflection when we think through them. Reflection secures our identity and calibrates our stance in the reality surrounding.

In creating tools for Creative Thinking, I have tried to consider the way they can provide a time and space for reflection in its social, personal, cognitive and emotional facets.

Asynchronous collaboration that does not demand face to face interaction, but that allows one to take one's time; the ability to contextualize creation by using objects and the environment as material for creation; the possibility of collaborating with people we would not normally do so; the capacity to go back and reflect on the creative process through documentation and the access to different layers of thought have been considered. (Rosenbaum, 2009)

Flexibility in Vehicles and Levels of Thought

Flexible thinking refers to the ability to fluidly switch vehicles of thought and to fully make use of the advantage one has over another. A vehicle of thought is not thought itself, but the way you represent thinking to your consciousness. They can take any shape; from sketching to mathematical models. (McKim, 1972)

Having access to a variety of vehicles of thought offers a much wider spectrum where to look for solutions to problems or derive conclusions from. Having flexible thinking is of great advantage when facing unknown circumstances, as it makes for a resourceful mind that is more likely to be self-sufficient and adaptable.

A flexible mind should be able to recognize the different layers at which we operate, unafraid of plunging into the subconscious, dwelling in emotions, and bringing it back to rational thought. It should also be able to smoothly transition between vehicles of thought, being capable of making the most of the offerings of each.

Our educational system though, has placed too much focus on language as a vehicle of thought, and while elementary and incredibly powerful, it has taken attention from visual thinking, a fact detrimental when trying to exercise a flexible mind since adhering to one vehicle tends to limit our sources for acquiring knowledge.

"With its ability to facilitate holistic, spatial, metaphoric, transformational operations, (visual thinking) provides a vital and creative complement to the reasoning linear operations built into the vehicle of language." (McKim, 1972)

Drawing and graphical representations are powerful tools for creative thinking. When we draw, we practice our perceptual capacity, our inner imaginary and our graphical skills to convey. Visual thinking requires us to see, imagine and draw. Drawing also provides record and detail, giving us what memory can't: the power to compare.

Tangible thinking on the other hand, steps out of the perceptual realm of visual thinking and into the object-oriented acquisition of knowledge; touching upon Piaget's constructivism and Papert's constructionism.

According to Piaget, we construct knowledge not only by refining perception, but constructing relationships between objects. Attention to texture and detail found purely in perception not being enough, this features must be situated within the spacial-temporal before having cognitive meaning. Constructivism states that physical manipulation permits understanding by investigating how an object (not necessarily a physical object, but an object of thought) transforms in relationship to itself and to the observer.

Papert, takes the tangible, kinetic at heart saying that knowledge is better acquired when we physically manipulate objects, “Learning by making.” The tangible artefact becomes a springboard for reflection by being an item that can be shared. (Papert, 1980)

Dreaming as Constructing

The activity that happens under the conscious level usually uses visual imagery to make itself understandable to the conscious level, otherwise known as autonomous imagery and being the dream the clearest example.

When we sleep, we create a visual landscape that does not necessarily follow the moral nor the physical rules of the waking reality we inhabit. In this sense, the dream provides an interesting window into object relating. In the dream the dreamer dreams itself, and the visual imagery abides by the aesthetic: the transformation of the thematic by the poetic.

When dreaming we create a stage where we play our own puppet with the added benefit of being able to bend space and time.

Although for the most part we are unaware that the landscape we inhabit is product of our mind, this is exactly what makes it all the more interesting, since it is not only the narrative that matters, but also the choices made to convey the message.

Dreaming goes beyond being a vehicle to self-knowledge. It is also an aesthetic experience. In that I like to compare it to what Turner would say about performance: ...” not only a reading of experience, but an interpretative reenactment of experience” (Turner, 1987)

The dream’s visual imagery and the freedom to “bend the rules” whether spatial, temporal or moral when manipulating objects, be they physical or objects of thought, (I was sweeping the clouds to let the sun come through, fireworks melted in the sky like honey drippings, I was hiding inside the skin of a bear, I was walking on a tight rope over my roofless childhood home, I held a forest in my hand) offers a rich ground where to reflect on our way to construct knowledge, both in the constructivist and constructionist sense. Furthermore, it demands a wake inquisitive mind: “Veiled in enigma, the dream invites curiosity!” (Bollas, 1987)

Reflection in Reflexion: Distorted Mirrors

Not only is keeping a flexible mind important to creative apperception, it also fosters empathy by offering different vantage points. When we are able to see the familiar from a different point of view, we create knowledge and appreciation for what we take for granted or promote change for what we dislike.

Victor Turner suggests that: “we should try to find out how and why different sets of human beings in time and space are similar and different in their cultural manifestations; we should also explore why and how all men and women, if they work at it, can understand each other.”

The externalization of an internal thought provides an object for critical contemplation that can be shared, interpreted, re-interpreted or mis-interpreted. In the practice of this we create new modalities of perception that might lead to the individuals re-discovery, as well as cross-cultural commonalities that transcend local realities and question stereotypes.

Collaboration is a performative act that requires negotiation of understanding. Just as we use different vehicles of thought to come to the solution of the same problem, we choose different means to convey message, going beyond words and extending the symbolic repertoire to our sensory entirety. It is not only in the material but in the use of the material where personal style, moral stance, skill, and aesthetic choices are revealed.

Victor Turner regards the variance in means of expression as a hall of “magic mirrors” in which social problems, issues and crises are reflected, and that, when shifted to a different genre, illuminates different facets, making scrutinization possible and “accessible to conscious remedial action.”

This resonates with what Bollas has to say about the dream experience, calling the dream text a primordial fiction and the dream space a theatre stage for an interplay of self and Other. This all occurring in a setting where thought is transformed to imagery.

By building a bridge over the big divide, we all benefit from enjoying the kind of knowledge that is only acquired when we collaborate with people that we would not usually think we would.

Quoting Victor Turner: “mirror distortions of reflection provoke reflexivity.” (Turner, 1982)

Tools for Reflective, Creative Thinking

Here I describe two tools designed to situate computation in cultural and material contexts that attempt to seamlessly foment access and fluidity between levels and vehicles of thought.

Calliope: Vehicles of Thought

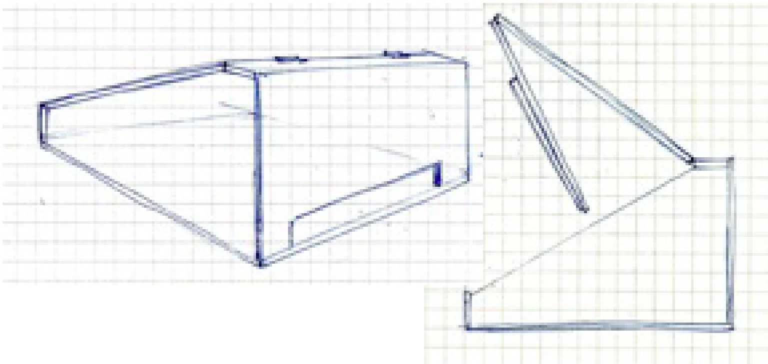
Calliope, is a portable, scalable stage for collaborative, cross-cultural, cross-generational storytelling. It incorporates analog and digital techniques as well as bidirectional capture and send of media, offering co-creation among peers whose expertise may not necessarily be in the same medium. It also offers the possibility of integrating objects as objects, as characters or as background. Using a paper sketchbook as the primary interface, it makes an inviting platform by simplifying the interaction through the affordance of the sketchbook.

Calliope is composed of two or more networked "creation stations" allowing synchronous or asynchronous collaboration across distance. The creative expressions done with Calliope are not limited to graphical representation through two dimensional means. Because one can embed audio, mix analog and digital media and make use of any object; it reflects a much truer personality of the user than by being systems limited to one imposed medium. This diversity invites the user to look into its surroundings for inspiration or for conveyers. Thus, what we express through Calliope is contextualized and personalized.

Calliope is a tool where we can learn from others and ourselves through joint co-creation. This is in the hope of offering self-expression instead of self-description, a means that I find conductive to unhealthy and anxiety filled self-consciousness.

Inspired by the Reggio-Emilia Approach, which emphasizes the position of the child in relation to other children, to his or her family, and to the societal and cultural surroundings as fundamental to the building of the child’s identity, it was of crucial importance to make Calliope a networked platform that could help sustain the above statement by being a tool for group socialization that made everyone an equal participant by not requiring specialized skills, but instead honing diversity of approaches. (Edwards, et al. 1972)

Integrating history into the pages of the sketchbook in Calliope was crucial in making it a tool for learning through reflection. Calliope gives access to the history of any page in the sketchbook to the user without the need to interface directly with a computer. By placing the appropriate tag on the sketchbook, the system displays all the iterations made to that particular page. In this way, we can say that every page retains the history of what has happened to it. This gives us access to the negotiation of actions between collaborators, the evolution of thought process, the coming to understanding and the reaching of agreement.



Calliope: Design Sketches (Santiago Alfaro)

Calliope offers a stage for objects to become part of the user's narrative. Objects become performers through the animism of the user, and users become performers by using objects to tell their stories. The choice of objects is not less important. While sometimes the narrative is driven by the object, in others it is the object that serves the narrative and yet other times, the objects are placed just to be recorded, to embed the identity of the user in one way or another onto the narrative. Stamping hands and faces, and changing the way they look by altering the digitalized self-image by drawing over it or by accessorising it with objects in ways mostly not permissible in real life was an amazingly amusing thing to do.

Calliope: Action tags

Calliope was designed to support the inclusion of personal experience as an integral part of creative learning and to prime the acquisition of future positive experiences by being a tool for cross-boundary collaboration that promotes the individual's capacity to re-contextualize their environment to fit their creative endeavour, engaging the individual in its present.

Calliope: Back and front view

Pillow-Talk: Levels of Thought

Pillow-Talk was designed as a tool to promote fluidity in levels of thought. It considers sleep as a time for dreaming, and dream as a time for identity consolidation (Jouvet, 2001). Furthermore, it resorts to the visual imagery that is created every night, by all of us in our sleep as a universal, primary source of self-reflective, creative thinking.

Maslow talked about two types of creativity: primary and secondary. He referred to the secondary kind of creativity as the one exerted when working with others and with the sources of others, and of primary creativity, he said, it is the one that resides in the "depths of human nature" not known to most people not only because it lays so deep, but because: "This is something that we not only don't know about but that we are afraid to know about." This primary creativity, he continues, is a heritage from every human being; a common and universal thing and visibly present in healthy children but repressed in most adults, only accessible if one digs deep (Maslow, 1971).Pillow-Talk aims to bring primary creativity to the fore-front.

We exercise what Christopher Bollas rightly added to Freud's vision of the dream: an "intrasubjective rendezvous", where we are both dreamer and dreamed, the object of the subject in a stage created by the aesthetic consideration of transforming thought into fiction. (Bollas,1987)

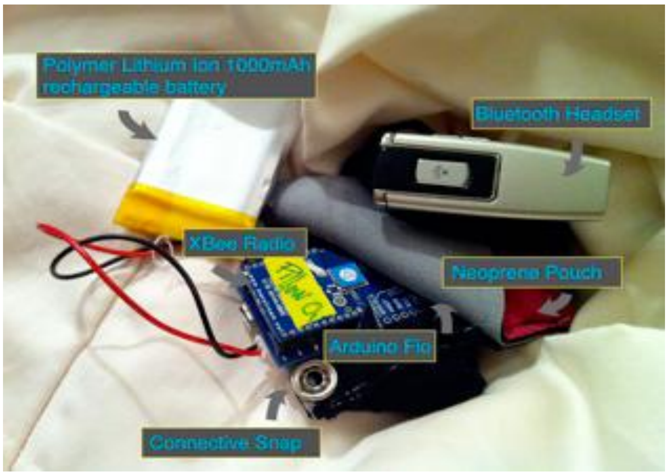
The dream is to me, the safest stage where to test knowledge, corroborate theories and create new ones. We wake up from an intense dream surprised at our own ability to resort to ingenious ways of solving problems, and while some might never work in waking life, they nonetheless did in their own context. We are freed from physical and moral constraints when we dream, we play under rules we create on the go, we are constantly constructing worlds!

Pillow-Talk: switch embedded in pillow

It has been said that dreams were the source for a wealth of inventions and discoveries, brought about by the ability of creative folk to move between conscious and unconscious thought seamlessly. Penicillin, the sewing machine, the atom structure among them (Barrett, 1993). But being able to find the solution in the dream requires not only remembering the dream; solutions are sometimes presented in a guise which requires a conscious flexible mind, as they might not be easily deciphered by the bounds of waking life.

Pillow-Talk attempts to make use of ubiquitous computing devices with reality-based interaction. Dream recall does not come easily for most people; most advice for recollection suggests keeping pen and paper close by. But sitting up, turning a light on or just simply moving is counterproductive to reminiscing. Stillness is crucial for recall, as even a slight movement is enough to make the dream evaporate from ones mind.

Pillow-Talk provides a seamless interface to prime recall and aid capture, minimizing the risk of distraction. To record a dream, one simply has to squeeze the pillow and start relating. Once captured, the dreams are time-stamped and saved onto ones computer for later use in whatever way one might see fit: for inspiration, analysis, self-reflection or mere curiosity. As an addition to capture, my colleague David Cranor designed a playback device, the “Firefly Jar”. The jar is a Mason Jar made to look like fireflies have been kept in it. Once recorded, the jar flickers, the dream stored and played back when opened, providing an evocative, tangible visualization tool. (Portocarrero et.al, 2011)



Pillow-Talk: module parts

The digitized dream allowed by Pillow-Talk, unlike a dream diary, gives the user the potential to analyse dreams over time, qualify and quantify themes, characters and emotions.

Speech to text recognition could allow data analysis, revealing common themes not only presented in the particular user's dreams, but among different users. Pillow- Talk could serve as a powerful tool to bring further insight into the fears and desires of a determined culture or generation as interpreted through their dreams and the aesthetic choices made to convey them. As Joseph Campbell puts it: "Myths are public dreams, dreams are private myths...dreams talk about permanent conditions within your own psyche as they relate to the temporal conditions of your life right now." This could potentially relieve any sense of alienation by illustrating that every individual problem should be seen in reference to the human situation as a whole.(Campbell, 1988)

Pillow-Talk sparkled interest for unexpected uses in various fields. Image Rehearsal Therapy (IRT) is a practiced and successful technique to treat recurring nightmares in Post-traumatic stress disorder (PSTS) victims that requires the dreamer to reframe the nightmare into a positive dream by imagining and repeating the desired outcome before going to sleep. (Greiger, et al. 2006) (Barry 2006) (Talbot 2009) (Kershaw 2010)

Other studies suggest that nightmare recurrence diminishes when the dreamer is conscious of sleeping under observation. Pillow-Talk could be said to be an inhibitor of bad dreams and a primer for recall.

Pillow-Talk is meant to be a personal tool for self reflection by bringing to conscious awareness the dream not only as a "road to the unconscious" but as an aesthetic lived experience, a product of creative mind common to all and which we go through every night. Pillow-Talk hopes to capture the detail of this imagery, for the aesthetic choices made reveal as much as the dream narrative.

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Networking constructionism and social semiotics in order to investigate students' bodily engagement with tasks in three-dimensional space

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Abstract

In this paper we aim to address the problem of fragmentation of theoretical frameworks within the field of mathematics education with technology while exploring the potential of turtle metaphor for students' meaningful engagement with angle in three-dimensional (3d) space. We developed cross-case analyses of two experiments: the one took place in the Greek context under a constructionist theoretical perspective and the other one was conducted in the UK context under a social semiotic perspective. The analysis indicates that the aforementioned method enhances our efficiency to capture tacit aspects of theoretical frames which nevertheless have an important bearing on analyses and knowledge emerging from the research experiments.

Keywords

Turtle metaphor, angle, 3d space, constructionism, social semiotics.

Introduction

The study of 3d objects (e.g. angles, 3d shapes) is known to be an obstacle for many students beginning to study 3d geometry. This is an area of mathematics in which students' informal ways of experiencing shape and motion within the three-dimensional world around them are excluded by the current teaching approaches in schools. Common approaches within the school curriculum provide relatively limited forms of experience, often relying almost exclusively on paper-based 2d representations of 3d objects. In particular, we note issues identified by research in relation to identification and operation with angles (Clements & Battista, 1992) and coordination of the various facets of the angle embedded in the physical contexts of corner, turn and slope (Mitchelmore & White, 2000). The development of new modes of representation within specially designed technological tools has generated further interest in the area of 3d geometry. As for angle, one of the prime affordances of such tools is the multiple linked representations designed to make different aspects of angular relations more accessible and meaningful to students. For instance, Logo-based computational settings integrate dynamic aspects of angle as turn with symbolic registers provided by Logo within a differential geometrical system (Papert, 1980). Existing research suggests that interaction with 2d Logo-based computational environments can be a fruitful context to challenge students' intuitions and ideas about angle as turn come into play through the turtle metaphor (Magina & Hoyles, 1997, Kynigos, 1997). More specifically, these studies seemed to adopt a body-syntonic approach to mathematics learning according to which construction of mathematical meaning could be considered as interrelated with students' sense and knowledge about their own bodies (Papert, 1980). This connection to personal bodily knowledge is operationalised through ‘playing turtle’, either literally by walking along a path or metaphorically in the imagination. In the research reported in this paper the students worked with a digital medium called *MaLT (MachineLab Turtleworlds)* which integrates a 3D Turtle Geometry, driven by a specially designed version of Logo with variation tools for dynamic manipulation of graphically represented mathematical objects (Kynigos et al., 2009).

Our main research aim was to explore the potential of MaLT as a context to investigate students' construction of meanings for angle in relation to 3d geometry. However, extension of Logo to 3d space, which is close to our physical experience of the world, raises new issues related to the extent to which the ‘playing turtle’ metaphor can be adaptable and relevant in this context. Thus, it can be seen as an opportunity to reconsider the role of bodily engagement in mathematics teaching and learning, taking into account the recent research interest in the use of gestures in mathematics education. Much of this has focused on the gestures used by students, analysing the contribution made by gesture to learning and mathematical meaning making (e.g. Radford, 2009). In considering gestures used by teachers, studies have shown teachers and students making shared use of gestures initiated by student communication efforts (Arzarello et al., 2009; Maschietto & Bartolini Bussi, 2009) and teachers using deictic gestures as mediating resources (Bjuland et al., 2009). Taking into account that bodily engagement in general and gesture in particular constitute an interesting characteristic when considering learnability of mathematics, here we report research aiming at shedding light on the potential of turtle metaphor through the use of MaLT to facilitate students' meaningful engagement with angle in 3d space. Yet, it seems difficult to really appreciate this potential, since it is needed to take into account the visions provided by specific theoretical frameworks in technology enhanced mathematics, and because of the fragmented character of these frameworks (Artigue, 2009).

Our aim in this paper is to combat fragmentation, trying to connect visions based on different theoretical perspectives. We have chosen the metaphor of networking theoretical frameworks and the idea of combining and coordinating frameworks “for the sake of a practical problem” (Prediger et al., 2008 p.172). We draw on data from an experimental teaching programme, conducted as part of the ReMath project (Representing Mathematics with Digital Media, European Commission FP 6, IST4-26751). More in particular, we reflect on the role played by theoretical frames in two teaching experiments designed and implemented with MaLT by two research teams working in different national and didactic contexts under different theoretical orientations. The first one was conducted in the Greek context by the University of Athens Educational Technology Lab (ETL) project partners under a constructionist theoretical perspective. The second one took place in the UK context by the Institute of Education (IoE) project partners through a social semiotic approach. The question we aim to tackle is: what new insight about the potential of turtle metaphor through the use of MaLT might be gained from contrasting different research studies carried out by researchers working in different research and didactic contexts under different theoretical perspectives? As a way to combine/coordinate the two frameworks we were engaged in the task of developing cross-case analyses of the conducted pairs of experiments, i.e. a unified associative/comparative description of two studies by way of constructionism and social semiotics. We introduce briefly the main ideas of the two frameworks and then we report on the teaching experiments. In the analysis, we first highlight the elements of an analysis from each theoretical perspective. Then, due to space availability, we demonstrate a comparative commentary on the two analyses only from a constructionist point of view.

Constructionism and multimodal social semiotics

The main theoretical framework adopted by the ETL team is constructionism (Papert, 1980, Harel & Papert, 1991). A fundamental construct of ETL's constructionist perspective is *situated abstraction* (Noss & Hoyles, 1996) that addresses the nature of concepts and the way in which they are formed**.** According to this theoretical tool, abstraction is seen as a process of layering meanings on each other, rather than as a way of replacing one kind of meaning (concrete, referential) with another (abstract, decontextualised). The idea is that students could web their own thinking by communicating with and through the computational tools and shaping them to fit their own purposes, including the need to communicate with others. In the ETL view, situated abstraction can be seen as a physical/intellectual context providing new resources for the learners to (re)think-in-progress while exploiting the available tools to move the focus of their attention onto new objects and relationships within the setting, while maintaining their connections with existing ones (Noss et al., 1997). ETL used MaLT as a means to engage students in making connections between static and dynamic contexts for experiencing angle in 3d space.

The primary theoretical framework adopted by the IoE team is multimodal social semiotics (Kress et al., 2001). Although originating in linguistics, this theoretical framework challenges the primacy of language as a means of communication and meaning making, highlighting the different potentials for meaning offered by different modes of communication and various available semiotic systems (O'Halloran, 2005). Multi-modal and multi-semiotic environments allow participants many opportunities for making meanings with the representations available to them and choices about the most apt representations to employ in order to communicate their desired meanings. As for mathematical communication, IoE team adopts a perspective which recognises the multimodal nature of communication and the importance of studying the contributions made by different modes of communication and representation. Kress et al.'s (2001) multimodal analysis of communication in science classrooms shows teachers and students making use of a "complex ensemble" of modes, including gesture alongside speech, writing, images, etc. In this vein, IoE team views learning mathematics as learning to participate in specialised mathematical forms of discourse which includes recognition of how the specialised discourse is distinct from others, including the everyday. The objective guiding the IoE research was to investigate the meanings students made for angle in relation to 3d geometry through their semiotic activity in the context of working with multiple modalities of resources.

The computer environment

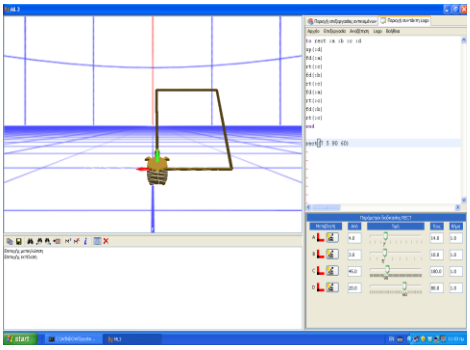

Figure 1: A rectangle in MaLT.

MaLT (Kynigos et al., 2009) is a programmable environment designed to extend Turtle Geometry to 3d. It consists of three interconnected components (see Figure 1): the Turtle Scene (TS), the Logo Editor (LE) and the Variation Tools. The available version of Logo provides an extension of Logo commands in 3d space including two new types of turtle turns: 'UPPITCH/DOWNPITCH n degrees' ('up/dp n') which pitches the turtle's nose up and down on a plane perpendicular to the one defined by right-left turns and 'LEFTROLL/RIGHTROLL n degrees' ('lr/rr n') which moves the turtle around its own axis. MaLT provides variation tools which afford dynamic manipulation of variable values. Figure 1 shows the Uni-dimensional Variation Tool (1dVT) whose main part consists of 'number-line'-like sliders (see Figure 1), each corresponding to one of the variables used in a Logo procedure.

Methodology

The study was conducted as part of a programme of 'cross-experimentation' (Artigue, 2009) in which the designers of the software (in this case ETL) and another 'alien' research team (in this case the IoE team) designed and conducted separate teaching experiments in their local contexts.

The ETL experiment took place in a secondary school with one class of twenty 7th grade students (13 year-old) and one experimenting teacher who acted also as a researcher. The class had eighteen teaching sessions in all with the experimenting teacher over two months. The pedagogical plan aimed at engaging students in knowledge building activity with some degree of autonomy independently of the standard curriculum and, indeed, deliberately by-passing traditional teaching approaches. Task 1 engaged students in developing their 3d sense of motion (i.e. simulating the take-off and the landing of an aircraft in MaLT with the use of a concrete model of an aeroplane). In the next three tasks angle was approached through the simulation of 3d geometrical objects which involve turning often encountered in everyday physical angle situations. In particular, in task 2 students were asked to construct rectangles in at least two different planes of the TS simulating the windows of a virtual room. In tasks 3 and 4 students were asked to develop or to correct parametric procedures so as to simulate the opening and closing of a door (task 3) and a revolving door (task 4). In classroom observation a participant observation methodology was adopted. The main corpus of data included video-recorded observational data, researchers' observational notes as well as the sorting and archiving of the corpus of students' work on and off computer. In analyzing the data we looked for episodes where meanings related to the visualisation and conceptualisation of the notion of angle in the simulated 3d geometrical space were expressed by the students. In most cases (e.g. episodes involving actors' bodily engagement), we base our analysis on the joint study of the transcribed interactions with the available video recordings.

The IoE experiment was conducted in a state secondary school in London with a Year 8 class (aged 12-13 years). The students had no previous experience with MaLT or other forms of Logo. The IoE pedagogical plan was designed to engage students with representations of 3d shape through designing and constructing a virtual building that would be of use to the school or wider community (e.g. a sports hall). The IoE tasks were similar to those developed by ETL but there were three distinct contextual differences: (a) the IoE team used a range of both traditional and innovative representations (e.g. students' use of multilink to reconstruct buildings from isometric drawings or to construct buildings through the use of plans and elevations); (b) the educational goals of the tasks remained clearly within the standard curriculum; (c) the students involved were marginalised within the school and broader educational system and had many difficulties – both social and mathematical – engaging with the planned activities. A sequence of nine lessons was taught collaboratively by the class teacher, the researchers and a student teacher attached to the class. In each lesson a video record was made, focusing on the teacher or researcher during whole class interaction and on a selected student or group of students during individual or group tasks. The video aimed to capture gestures and the various visual and physical resources available, including the computer screen when in use. Episodes in which use of multiple semiotic modes was evident were selected for transcription (see Morgan & Alshwaikh, 2011 for more details).

Bodily engagement through gestures

One common theme of the two analyses concerned the students' and/or teachers'/researchers' use of gestures that emerged during the implementation of tasks in the classroom. One significant type of gesture was a set of stereotyped hand and arm movements, often associated with use of the terms *turn*, *pitch* and *roll* and the associated Logo instructions (see Figure 2). They may be considered *iconic* gestures (Roth, 2001), in that each bears a visual resemblance to the anticipated trajectory of an object moving in 3d space.

ETL analysis: Gestures scaffolding meaning generation for angle in 3d space

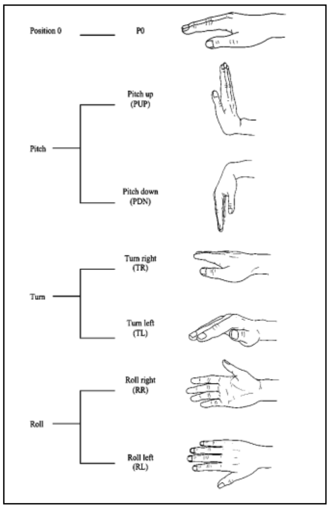

Figure 2. 3d turn gestures.

Bodily engagement in the Athens experiment was related to the students' informal or spontaneous use of iconic gestures. It thus constituted one aspect of the ETL analysis which emerged as a coherent part of the students' construction of meanings for angle in 3d space interrelated with their attempts to describe the turtle's navigation as well as to conceptualise the role of 2d representations in forming angular relationships in 3d space. In the next episode the students' use of gestures appeared as part of their struggle to understand the ways by which the combination of the new turning commands in the Logo language could affect the manipulation of a 2d geometrical figure so as to construct the simulation of a door. We note that the episode took place before students were asked by the researchers to construct a door simulation which constitutes one activity of the ETL pedagogical plan (task 3). Initially Group B students constructed a rectangle with three variables on the horizontal 'ground plane' (Table 1, Procedure 1). Having recognised the way in which the up(90) command affected the position and the orientation of the turtle, they inserted the command up(90) at the beginning of the respective procedure and constructed the same rectangle on the 'screen plane' which -in mathematical terms- is perpendicular to the 'ground plane' (Table 1, Procedure 2).

to rect :a :b :c	to rect :a :b :c	to rect :a :b :c :d
fd(:a)	up(90)	up(:d)
rt(:c)	fd(:a)	fd(:a)
fd(:b)	rt(:c)	rt(:c)
rt(:c)	fd(:b)	fd(:b)
fd(:a)	rt(:c)	rt(:c)
rt(:c)	fd(:a)	fd(:a)
fd(:b)	rt(:c)	rt(:c)
rt(:c)	fd(:b)	fd(:b)
end	rt(:c)	rt(:c)
	end	end
Procedure 1	Procedure 2	Procedure 3

Table 1: Logo procedures for rectangles.

When trying to concretise the new position of the rectangle in 3d space one student used her hands so as to mimic the movement of the turtle from the surface to the 'screen plane' (Figure 3).

R: What happened to the turtle with up(90)?

S1: [Whole rt arm horizontal P0, hand moves up PUP 90°] It [i.e. the turtle] took it [i.e. the rectangle] that way.

R: If we put 45, what would have happened?

S1: [rt hand moves up PUP 45°] It [i.e. the rectangle] would be nearly in the middle.

R: If we put 50;

S1: Ok, not in the middle. [rt hand moves up PUP a bit more] A bit more than that.

The dynamic character of student's bodily engagement in the simulation challenged both of them to try to visualize it on the screen. S1's iconic gesture here signified the actual move of the recrangle in 3d space. At that time, this kind of gesture seemed to provide a basis for S1 to make sense of the type of turtle move in 3d space, to consider it as varied and to link it to the relevant Logo command (uppitch). So, S1 afterwards had the idea to replace the value 90 in the command up(90) (Table 1, Procedure 2) with a new variable :d to see what would happen. Then, dragging on the slider of the variable (:d) in 1dVT had the effect of the figure dynamically moving upwards – downwards visualising in that way the dynamic move of the rectangle in different planesas well as the preceding uppitch-downpitch gestures made by S1.

Figure 3

S1: [Moving the slider (:d)] Look! If we move it [i.e. the slider (:d)] upwards it [i.e. the rectangle] raises ... If we move it [i.e. the slider] downwards it descends.

In the evolution of the episode the students had the idea to insert in the procedure a roll command so as to simulate the continuous move of a door. The sequence of what happened next is as follows. Initially one of the students substituted the command up(:d) (Procedure 3) with one of the roll commands (rr :d). Moving the slider (:d) then she realized that the direction of the axis of rotation was perpendicular to the screen plane ('*it turns as a wheel*' she said) (Fig. 4, on the left).

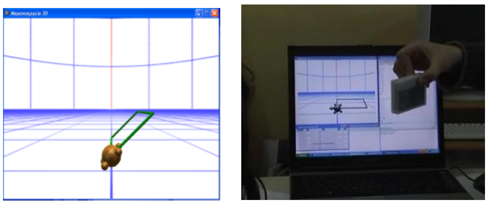

Figure 4: A 'rolling' rectangle (left) and a video-cassette as 'rectangle' (right).

At this phase students continued to 'play turtle' to identify the type and the sequence of the turtle turns which would result in the desired simulation. In doing so, they faced difficulties in imagining -and thus mimicking- in which way the turtle 'moves' the rectangle in different positions and directions in 3d space. They found efficient to rehearse the move of the rectangle with the use of a concrete 3d object, in this case a video-cassette, so as to visualise the change of planes of the rectangle as a result of the change of the initial position of the turtle in 3d space (Fig. 4, on the right). So, students realized that initially the rectangle needs to be raised up and then turned ('rolled') on the right. Modifying accordingly the Procedure 3 students used one more variable in the command rr(:e) that was inserted after the initial command up(:d). They subsequently achieved to simulate the 'opening-closing' door (Fig. 1) by dragging the slider (:e) on the 1dVT after selecting the value 90 for :d.

The above episodes indicate the conceptualisation of angle as a spatial visualisation entity interrelated with move through different planes 'inside' the TS. We see a dynamic aspect in students' bodily engagement in these episodes. While 'playing turtle' with the use of hands and/or the cassette, the students defined the dynamic manipulation of the rectangle by using position and heading of the turtle which seemed to 'coincide' with the rectangle (i.e. the turtle appears in some way to 'carry' the rectangle). Actually, the students oscillated between two frames of reference: (a) the world frame: defined in terms of the fixed directions 'up' and 'down' and (b) the vehicle frame: typically associated with the orientation of a moving entity, here the turtle. In the initial construction on the 'ground plane' the vehicle frame of reference coincides with the world frame of reference. In other words, the 'up' in relation to the turtle's position coincides with the 'up' of the simulated 3d space. Thus the students' gestures at that time integrated both iconic and deictic features: they command the turtle to move 'upwards' to the 'screen plane' and indicated this through S1's gesture showing also the 'up' direction in the everyday world. Here the desired drawing concerning the transition of the designed rectangle to the 'screen plane' coincides to the required type of turtle turn. At the same time, the students enacted certain situated abstractions concerning the position of the rectangle in 3d space in relation to the turtle's continuous turning and finally they were able to express these dynamic movements/turns with the use of variables. Thus, students were able to coordinate turtle's/rectangle's turning in the 3d space with the formal (Logo) notation and the dynamic manipulation provided by the available tools. We highlight the episodes in order to show the evolution of students' purposeful use of the available tools as situated in a larger process of abstracting angle as a spatial visualization concept *within* the setting by making connections between existing and emergent views of angle in 3d space.

IoE analysis: Imag(in)ing 3d movement with gesture

As we started to view the video data collected during the London experiment, it was noticeable that the teachers and researchers made extensive use of iconic gestures in an apparent attempt to support students' planning and execution of constructions. This set of gestures constituted a new semiotic system, linked with, but not identical to, both the linguistic description of movement and the symbolic system of Logo. Students also made use of these and other gestures to support their communication about turtle movement. Although the students used 'these' gestures to indicate that their hand and arm movements resembled those used by the teachers/researchers, we believe, as will become apparent, that the students made use of them in different ways, thus construing different meanings.

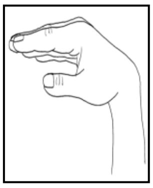

Figure 5: down pitch.

Episode 1**:** In the introductory session with MaLT, one of the research team introduced the notion of turtle movement using a toy aeroplane (i.e. simulation of the plane taking off). While navigating the aeroplane, the teacher accompanied the physical movement of the hand/aeroplane with a verbal description, using and stressing the terms pitch, roll and turn in synchrony with the associated gestures. In a later lesson, recognising that some students were still having difficulty distinguishing between these different kinds of turn, the class teacher used her arm and hand to act out the role of the turtle drawing a 'door' under instruction from the class while a researcher entered the Logo instructions into a computer, displaying the resulting turtle path on a large screen. The teacher was careful to follow the conventions of the gesture system in order to emphasise the relative nature of turtle movement. Thus, for example, she turned her hand in a down pitch gesture when given the instruction to go down, even though this resulted in her hand pointing horizontally as in Figure 5. This resulted in conflict for students between their intended outcome and the visual feedback provided, leading to rapid self-correction of the Logo instructions.

Episode 2. Student T, having constructed one rectangular wall, was trying to construct a second wall perpendicular to the first. She explained what she was trying to draw using language and gesture.

1	here	*whole rt arm vertical P0, palm facing away from body, moves up in direction of fingers*	
2	turn here	*TR, arm moved in direction of fingers (maintaining TR position)*	
3	turn here	*attempt to move rt hand TR again (too difficult?)*	
4		*switch to lt hand, arm horizontal pointing rt, hand PDN (fingers pointing down)*	
5	turn here	*moves forearm clockwise, hand still PDN (fingers pointing left)*	
6	but I want it to come forward	*turns arm (awkwardly) so that, hand still in PDN position, fingers point towards body*	

Table 2: T imagines a wall.

The switch (lines 3-4) between use of right and left hands appears to be a response to the physical difficulty of achieving the desired position with the right hand. We consider what remains the same and what is changed with this switch of hand. The switch allows T to maintain the direction in which the fingers are pointing (down). This may be taken to represent the turtle heading within the vertical plane parallel to the screen. However, in switching arms, she changes the relationship between arm and hand from a *turn* gesture to a *pitch* gesture. We use *turn* and *pitch* within the conventions set up by the teachers/researchers and the Logo language, not to suggest that T associates her gestures with these terms. On the contrary, she does not appear to attach any significance to the distinction, focusing solely on the position of her hand and the direction in which her fingers are pointing in order to describe the intended turtle movement. While she is to some extent 'playing turtle' with her hand, she is defining the turtle's movements by using position and heading at the corners of her imaginary wall rather than by using turn and distance as required by the Logo language. The use of the turn and pitch gestures is thus not supporting her move into using Logo code and may indeed have made her communication with teachers/researchers less effective.

In considering the difference between the ways in which teachers/researchers and students were using the 'same' gestures, we distinguish between the two notions of *imaging* and *imagining*. We define *imaging* as using an iconic gesture to create an image of the construction of the turtle path. The movement of the hand mimics the movement of the turtle: the forearm is held parallel to the current heading of the turtle and the hand is moved to define the next heading. Thus the gesture indicating 'up pitch' is always relative to the current heading of the turtle. In episode 1, the teacher/researcher gestures were imaging the process of construction of the turtle path. In contrast, in episode 2 student T used apparently similar hand movements to construct a very different effect. For her, the relationship between forearm and hand did not appear to have significance, as she was willing to substitute a pitch down gesture with her left hand for a turn right gesture with her right hand. We characterise her use of gesture as *imagining*, referring to her mental image of the desired outcome of turtle drawing. Such use appears to have both iconic and deictic characteristics. In this episode, as in several other episodes of student gesture within the data set, the gesture points to the desired direction of movement in order to draw the desired outcome, rather than mimicking the required type of turn. Thus, for example, a movement in the 'up' direction (within the plane of the screen) might be indicated by use of the spoken word up accompanied by a 'pitch down' gesture. While it might appear at first sight that students adopted the specialised gestures employed by the teachers/researchers, the students' use and interpretation of these gestures may be closer to the resources of everyday discourse than to those of the MaLT microworld (Morgan & Alshwaikh, in press). The extra leap of imagination required to 'play turtle' as if in control of an acrobatic aircraft or perhaps in deep water with highly developed underwater manoeuvrability may be too great for genuine body syntonicity.

Commentary on the two analyses from a constructionist perspective

Comparing the ways in which both teams analysed the students' use and interpretation of gestures to support their communication about turtle movement reveals distinct differences. IoE interest in gesture arose from concerns about the ways in which students might make use of new semiotic resources offered to them by teachers/researchers and about the coordination of different semiotic systems. The IoE analysis highlighted differences in the meanings associated with the gestures by teachers/researchers and the students while 'playing turtle'. Teachers and researchers used specialised hand gestures to communicate with students about 3d movement. Students used the ‘same’ gestures but to communicate different meanings in relation to turtle movement. Whereas the *imaging* by teachers/researchers mimicked turtle movement in a kind of ‘playing turtle’ action, student use of gesture to *imagine* the outcome of the movement seems closer to deixis, pointing in the direction of movement from a viewpoint outside the turtle. Thus, IoE researchers focused on the relationships between the formal set of gestures related to Logo terms as used by teachers/researchers and by students while the relevance and importance of students' informal or spontaneous use of gesture has not been a focus of their attention in their study. Although it is apparent from the IoE analysis that the student engaging in the task did generate meanings about the notion of angle in 3d space, IoE chose to focus on the distance –actual and conceptual- between the students and teacher/researcher use of hand gestures and that the ‘playing turtle’ metaphor did not easily transfer into 3d context.

The ETL team’s interest in gesture emerged as part of the teams’ research focus on the students’ use of the available representations of MaLT to construct meanings for angle in 3d space. Under this perspective the ETL team aimed to address the relevance and importance of students' informal and/or spontaneous use of gesture as part of their attempts to achieve their goals in the given setting (e.g. simulating the opening-closing of a door). Thus, the team focused on how the available representations in MaLT served as a resourse for the students to challenge their engagement with the tasks –which involved the use of their bodies or other objects- to construct meanings for angle in 3d space. The meaning generation process in both the IoE and ETL experiment is perceived by ETL as being in close relation to the students’ hand gestures which most of the times were mimicking turtle movement in a kind of ‘playing turtle’ action. From the ETL perspective the episode 2 provided by the IoE team would have beeen analysed as part of the students’ attempts to conceptualise angle through a specific geometrical construction (i.e. vertical ‘walls’). For analysing the same episode, the ETL team would have been interested in identifying what was visualised on the screen and in which ways gesturing affected the subsquent students’ experimentation to complete or explore the current geometrical construction with the available tools as well as meaning generation for angle.

Conclusion

At the level of networking constructionism and social semiotics, the above comparative description of two analyses shows how such a process may reveal tacit aspects of theoretical frames which nevertheless have an important bearing on analyses and knowledge emerging from the respective research experiments. How for instance the two teams differing perceptions of the students’ active engagement in gesturing influenced the resulting analyses concerning meaning generation. A general overview of the commentary reveals that while the constructionist approach of ETL seems to illustrate the students’ abstractions providing insight into the mutual shaping of student/computer interaction (involving communication between the participants), the social semiotics perspective of IoE seems to illustrate the complexity of communication patterns that may affect the construction of meaning. This brings evidence that by combining constructionism with social semiotics, cross-analysis captures more efficiently the potential of MaLT as compared to the use of a single framework specific to a particular experiment. This is clearly a first step towards coordinating these approaches in order to get an integrated framework to analyse the potential of turtle metaphor into 3d context.

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Using Virtual Globes and GIS in Digital Geography Textbooks

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Abstract
Nowadays, the teaching of Geography in compulsory education integrates modern Technologies of Information and Communication (ICTs), such as Geographical Information Systems (GIS) and Virtual Globes. The capabilities of a GIS, like the ability to accurately map spatial locations, the multiple of ways to represent the different attributes and characteristics of geographical entities and the ability to create dynamic maps are undeniable. Virtual Globes combine satellite images with a variety of ancillary data, to support a large number of Earth Science applications. On the other hand, the integration within the different subjects and computer infrastructure of contemporary open ICTs provides opportunities for students to engage in innovative and creative learning processes. This paper presents the results of a study on the use of the Google Maps and Google Earth platforms to enrich the digital versions of Geography textbooks in primary and secondary education.

Keywords
Geography education, GIS, Google Api, Google Maps, Google Earth

Introduction

In the last decades, Geographical Information Systems (GIS), a set of integrated software programs designed to store, retrieve, manipulate, analyse and display geographical information, have emerged as an essential tool, playing a decisive role in a number of human activities of everyday life (Koutsopoulos 2005). GISs are therefore an important educational tool for primary and secondary education throughout Europe. They are relevant to many educational subjects, and particularly to Geography and geographical education (Klonari et al. 2009). Geography, as an interdisciplinary subject, lends itself to the introduction of innovative teaching and learning approaches via the use of ICTs. Specifically GIS, with its emphasis on digital information processing and analysis, can contribute greatly to the fusion of various geography-related disciplines that incorporate the spatial dimension (Patterson 2007). While GIS can have a significant impact on the teaching and learning of spatial thinking, it must be incorporated into a standards-based curriculum and used alongside other types of tools in the classroom (CSTS 2005).

GIS in Greek Schools

In Greek compulsory education, there is no direct reference to GIS in the formal curricula except for the case of the book of Geology-Geography of the 1st grade of lower secondary education (i.e. 12 to 13 year olds). Nevertheless, teachers familiar with the respective technology might sometimes refer to or use geo-informatics in class. According to the limited number of published researches carried out in Greece regarding the use of GIS in secondary education, not only do they formally not exist in the curricula and are therefore not used in teaching and learning, they also still constitute a 'black box' for most teachers (Klonari 2009). During 2011 and in the framework of the action called "DIGITAL SCHOOL: Specifying a Digital Educational Platform, Building and Operating an Educational Knowledge Base, Adapting and Annotating Learning Objects with Educational Metadata, Building the Infrastructure to Support Exemplary Teaching Practices and the Use of the Participatory Web", co-funded by the European Union and the Greek State under the auspices of the Greek National Strategic Reference Framework (NSRF), created teams, of primary and secondary education teachers managed by academics (professors), responsible for the development of learning objects with educational metadata for several subjects, including the subject of "Geography and Geology - Geography".

The goal of this research is to investigate ways of development of Digital Education Material which would enrich the digital edition of Geography school textbooks. Some of the learning objects which have been developed by the team are relative to GIS. Considering the fact that the teaching of GIS involves two aspects: teaching *about* GIS and teaching *with* GIS (Sui 1995), our approach is that students should have the opportunity to

- combine the learning objects with basic concepts of computer science;
- modify material and test their attempts and ideas;
- search for solutions to their problems, with "networking and engagement in research carried out by wider and disparate communities" (Kynigos 2007).

Google Maps Application Programming Interface (API)

Google launched the Google Maps JavaScript API in June 2005 to allow developers to integrate Google Maps into their websites. It is a free service if used in freely and publicly accessible websites. By using the Google Maps API, it is possible to embed Google Maps into an external website where specific data can be overlaid.

Virtual Globes - Google Earth API

One type of Internet-based GIS is Virtual Globes. Virtual Globes are similar to Desk Globes with the additional capability of simultaneously representing many different thematic views of the Earth's surface. They show spatial data at multiple scales and in multiple ways, including photos and videos. The user can seamlessly zoom into the data, rotate the view, and tilt the image to see the terrain in three dimensions. Virtual Globes display satellite imagery at various resolutions, aerial photos, topographic maps, elevation data, along with GIS layers like roads, administrative boundaries, points of interests, and place names overlaid on each other using a Web interface (Rakshit and Himmelberger 2008). The entire planet is covered, with around one-third of all land depicted at such high resolution that individual trees, cars, and the households of 3 billion people, can be seen (Rakshit and Himmelberger 2008). The Google Earth Plug-in and its JavaScript API allow users to embed Google Earth, a true 3D digital globe, into web pages. Using the API you can draw markers and lines, drape images over the terrain, add 3D models, or load KML files, allowing you to build sophisticated 3D map applications. Below we present examples, which represent categories of geography textbook enrichment in the Google environment.

KML files

KML (Keyhole Markup Language) is a simple XML notation for expressing geographical data. KMZ is a zipped KML file. Students can download KML files and open them with Google Earth locally. For example, and for the lesson of different kinds of positioning a place, explore the file gbg01_alexandroupoli.kmz that is free to everyone (e.g. Relative and absolute position).

KML embedded in web pages

By using the Google Earth Plug-in, a KML file can be embedded in web pages (e.g. European Seas).

Virtual Globe and Tours

Taking advantage of the "tour" feature of kml files together with representational capabilities, of depicting lines and displaying data, virtual tours can be constructed on the Earth’s surface. It uses the JavaScript language (e.g. Magellan’s expedition).

Figure 1. Magellan's expedition

Google Maps and Visualization of Geographical data

In this case, an interactive JavaScript application can be employed that connects the map area, (on the top of the screen in Figure 3) with a column graph (on the bottom of the screen in Figure 3). It combines the strength of a graphical representation of data with the accuracy of geographical positioning and the encyclopedias available on the internet. In the case of an area in Greece, for example, by clicking on any bar of the graph, a balloon emerges on the corresponding position in the map, with a relative link to the Greek version of Wikipedia. The code is open access and can easily be accessed directly from the browser (by selecting ‘view source’), modifiable and reusable so that the students can use it for another set of data (e.g. European mountains).

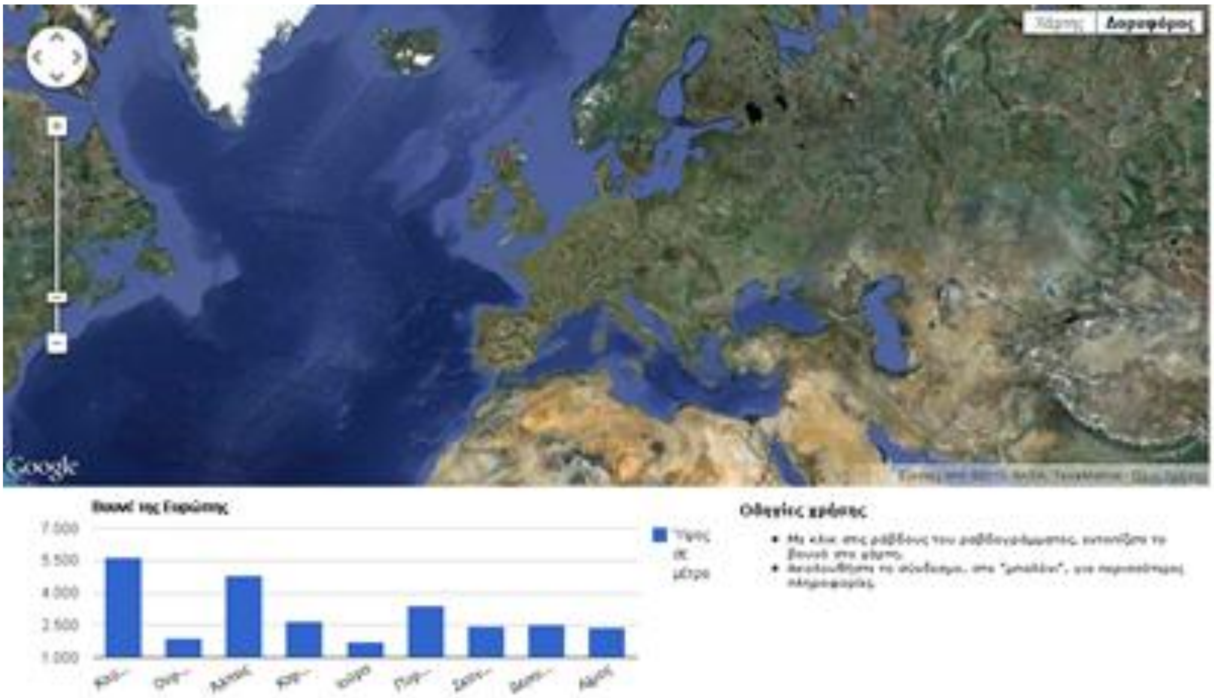

Figure 2. European mountains

Google Maps and Measurement Tools

Measuring different phenomena is an integral part of a geographer's profession. An application, in the Google Maps JavaScript API, is able to query and use the data stored in the data base the interactive Google Maps to produce graphical representations of such queries. For example, starting from the map area, students can trace any route, on land or sea, and see the height or depth of any point of the specific route in a graph (Height Meter Tool).

Figure 3. Height meter tool for a route

Conclusions

Geography lessons today can be supported by using the powerful and dynamic technology of GIS. The digital versions of geography textbooks should, therefore, incorporate the use of GIS. Teaching geography using such tools could allow the students to get involved with new technologies not only to visualize geography-related data; they can also investigate the existing databases and produce their own queries and graphical outputs, such as graphs and maps. Moreover, they also have the opportunity to engage with programming languages and other components of computer science and familiarize themselves with different aspects of human thought, as it changes under the tremendous impact of digital technology.

Web pages

European Seas. http://digitalschool.minedu.gov.gr/modules/ebook/show.php/DSGYM-B106/382/2534,9788/extras/gbg12_eu_europeanseas/index.html

European mountains. http://digitalschool.minedu.gov.gr/modules/ebook/show.php/DSGYM-B106/382/2534,9792/extras/gbg16_europeanmountain/index.html

Relative and absolute position. http://digitalschool.minedu.gov.gr/modules/ebook/show.php/DSGYM-B106/382/2534,9780/extras/gbg01_alexandroupoli/gbg01_alexandroupoli.kmz

Magellan's expedition. http://digitalschool.minedu.gov.gr/modules/ebook/show.php/DSGL100/418/2821,10662/extras/geocoder/MagellanTour.html

Height Meter Tool. http://digitalschool.minedu.gov.gr/modules/ebook/show.php/DSGL100/418/2821,10662/extras/geocoder/MultiAndDynamicHeightMeterC_GR.html

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Supersonicman – an informatics x physics project

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Abstract

In the paper, a student project is proposed where high altitude fall of a person in the air is investigated. The object is to answer the question if it is possible to reach supersonic speed.

Keywords

Constructivism, spreadsheet, model, Kittinger, fall

Introduction

In the paper, a project for grammar school student (age 17-19) is proposed where high altitude fall of a person in the air is investigated. The object is to answer the question if it is possible to reach supersonic speed. An interactive numeric model of J. W. Kittinger's legendary jump is created in Excel, based on the Euler's method which is clear and intelligible. No programming is used. Using the model, students can investigate the behaviour of the system and find the boundary or limiting cases. The project meets well the UNESCO's notion about ICT in secondary school (Anderson, 2002). It corresponds with 3 out of the 11 units of the module "Application of ICT in subject areas", which are: ICT in Natural Sciences, Modelling and Simulation, and Spreadsheet Design. The project is based on author's article (Benacka, 2011). Ideas for other cross subject projects (informatics x physics, informatics x mathematics) can be found in (Benacka, 2007, 2008, 2009, 2011b). The minimal ICT tools that the students will use in the project are: Internet to find the sources; word processor to write up the report; PowerPoint, to prepare the presentations, and spreadsheets as the key tool to develop the model. The choice of the spreadsheet is obvious – it is a widespread program that enables students to analyse scientific problems and find solutions without programming. Not only is it easy to use, but it allows using problem-solving and heuristic methods, which are close to talented pupils. While creating the model, students practise their spreadsheet skills, gain new ones, and get a better understanding of the modelled problem. This makes spreadsheet an excellent tool for constructivist learning.

High-altitude fall in the air

On August 16, 1960, USAF Captain (later Colonel) Joseph W. Kittinger carried out his legendary jump from the helium balloon Excelsior III at the altitude of 31,300 m. He reached the top speed of 274 m/s, which was 0.9 of the speed of sound at the altitude. His mass was 142 kg, from which 70 kg was gear. He fell as sitting in an armchair due to his inflated pressure suit. He had serious breathing difficulties between 27,400 m and 21,300 m due to the helmet that was pressing against his throat (Kittinger, 1960; URL 1). It has been the highest, longest, and fastest sky-dive ever made. According to some sources, the top speed was 319 m/s (Clash, 2003). That would be a supersonic fall at the altitude. Some time ago, an attempt was cancelled to break the sound barrier in fall (Tierney, 2010). The jumper was to fall in a special suit, head-to-earth, stabilized just with his legs and arms straighten back in a "V" shape. There is a question: Is it possible for a person falling in the air to reach supersonic speed, that is, to become a Supersonicman?

US Standard Atmosphere is a scientific atmosphere model (URL 2). The properties are in Tab. 1.

Layer *b*	**Altitude (km)** $z_b - z_{b+1}$	**Density** ρ_b **(kg/m³)**	**Temperature** T_b **(K)**	**Temperature lapse rate** L_b **(K/m)**	**Speed of sound** c_b **(m/s)**	**Name**
0	0 – 11	1.225	288.15	–0.0065	340.29	Troposphere
1	11 – 20	0.36391	216.65	0	295.07	Stratosphere
2	20 – 32	0.08803	216.65	0.001	295.07	

Table 1 US Standard Atmosphere 1976 up to 32 km

Values ρ_b, T_b, and c_b hold at bottom z_b of layer *b*. Temperature lapse rate L_b is constant within layer *b*. In layers *b* = 0 and *b* = 2, density $\rho(z)$ is given by the equation

$$\rho = \rho_b\left[1 + L_b\left(z - z_b\right)/T_b\right]^{-(\beta/L_b+1)}, \tag{1}$$

where $\beta = g_0 M/R$, $R = 8.31432$ J/(mol.K) is the gas constant, $M = 28964.61$ kg/mol is the molar mass of the air, and *z* is the altitude, where $z_b \le z \le z_{b+1}$. Remark: In layer $b = 1$, which is out of the interest, the density is $\rho = \rho_b\,\mathrm{e}^{-\beta(z-z_b)/T_b}$. Speed of sound $c(z)$ is given by the equation

$$c = c_b\sqrt{1 + L_b\left(z - z_b\right)/T_b}\,. \tag{2}$$

Acceleration due to gravity at sea level is $g_0 = 9.80665$ m/s². The acceleration at altitude *z* is

$$g = g_0\, r_0^2/\left(r_0 + z\right)^2, \tag{3}$$

where $r_0 = 6{,}356{,}766$ m is the effective radius of the Earth.

Weight $G = mg$ and drag $F_\mathrm{D} = 0.5CA\rho v^2$ (Marion, 1970) act on a body of mass *m* falling in the air, where A is the maximum cross-section area of the body perpendicular to the motion direction, ρ is the air density, *v* is the speed, and *C* is the drag coefficient dependent on the shape of the body. If the speed is subsonic (below about 0.8 of sonic speed = Mach 0.8), then *C* is virtually constant. If the speed is transonic (from Mach 0.8 to 1.2), then *C* increases rapidly. The resulting force *F* is

$$F = G - F_\mathrm{D}. \tag{4}$$

It holds that $F = ma$, where $a = \Delta v/\Delta t$ is acceleration and *t* is time. Substituting in Eq. (4) gives

$$\Delta v = \left(g - 0.5\,SC\rho v^2/m\right)\Delta t\,, \tag{5}$$

where $\Delta t = \mathrm{t}_{\max}/n$, and n is the number of subintervals of interval $\left[0, t_{\max}\right]$. It holds that $\Delta z = v\Delta t$. It holds at $t = 0$ s that $v = 0$ m/s and $z = h$. Then, speed $v(t)$ and altitude $z(t)$ are given by the equations

$$v_i = v_{i-1} + \left(g - 0.5\,SC\rho v^2/m\right)\Delta t\,,\; v_0 = 0,\; i = 1, \Lambda\, , n\,, \tag{6}$$

$$z_i = z_{i-1} - v\Delta t\,,\; z_0 = h\,,\; i = 1, \Lambda\, , n\,. \tag{7}$$

Equations (6) and (7) allow graphing the speed and altitude.

Implementing the model in Excel

The application is in Fig. 1. The graph is made over 5,000 points. The white cells are for inputs.

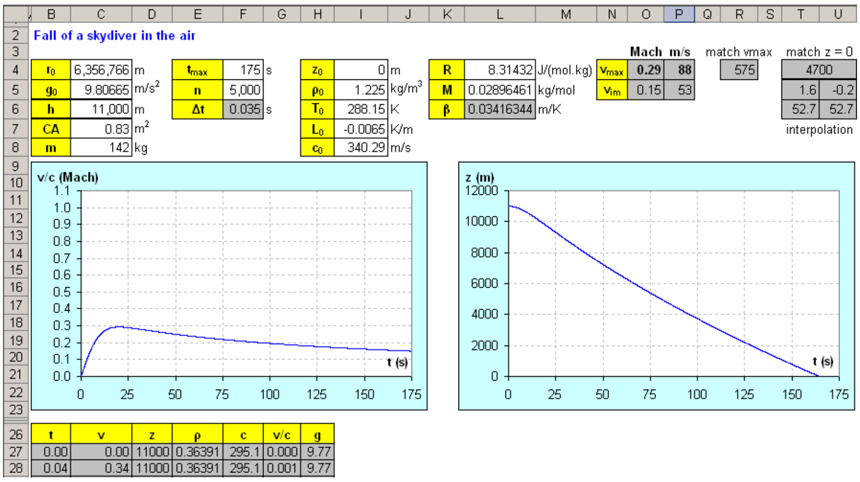

Figure 1. Speed and altitude of a person falling in the troposphere:
h = 11, 000 m, CA = 0.83 m^2, m = 142 kg, v_{max} = 88 m/s = Mach 0.29

Instead of C and A, product CA is inputted (see the next section). The grey cells contain formulas. In cell F6, it is =F4/F5. In L6, it is =C5*L5/L4. The model is in cells B27:H5027. They contain the following formulas (copied down as far as row 5027; the number of the equation is added):

```
B27 =0;    C27 =0;    D27 =C6
E27 =$I$5*(1+$I$7*(D27-$I$4)/$I$6)^(-$L$6/$I$7-1) (1);      F27=$I$8*SQRT(1+$I$7*(D27–$I$4)/$I$6) (2)
G27=C27/F27;        H27 =$C$5*($C$4/($C$4+D27))^2 (3);
B28 =B27+$F$6;    C28 =C27+(H27-0.5*$C$7/$C$8*E27*C27*C27)*$F$6 (6);   D28 =D27–C28*$F$6 (7)
```

The maximum of relative speed v/c is in cell O4 found by function MAX(G27:G5027). In cell R4, function MATCH(O4;G27:G5027;0) returns the ordinal number of the maximum. In cell P4, function OFFSET(C26;R4;0;1;1) returns the value in the cell shifted from C26 downwards by the number in cell R4, i.e., it returns the speed from the row where the maximum relative speed is.

The impact speed is calculated in cells T4:U6. In cell T4, function MATCH(0;D27:D5027;–1) gives the ordinal number of the null or last positive altitude (from D27 downwards). In cell T5, function OFFSET(D26;T4;0;1;1) gives the altitude. The next altitude is returned into cell U5 by function OFFSET(D26;T4+1;0;1;1). Thus, cells T5 and U5 contain the last nonnegative and the first negative altitudes. In cells T6 and U6, functions OFFSET(C26;T4;0;1;1) and OFFSET(C26;T4+1;0;1;1) give the speed from these rows. The impact speed, which is the speed at null altitude, is calculated in cell P5 using linear interpolation by the formula =T6–(T5–0)/(T5–U5)*(T6–U6). There is no sense to calculate the impact speed in the stratosphere (Figs. 2, 3).

Analysis of the fall

The application with the data for Kittinger's jump is in Fig. 1. Parameter CA was iterated until the maximum speed was 274 m/s, which gave CA = 0.83 m^2. It holds for a person that $C \sim 1-1.3$ (URL 3). Kittinger fell as sitting in an armchair with load on his back. If $C \sim 1$, then $A \sim 0.83\ \mathrm{m}^2$, which is acceptable Kittinger was in transonic range (above Mach 0.8) for 28 s from t = 29 s to t = 57 s. If C increased during this flight to $C \sim 1.3$, then $A \sim 0.64\ \mathrm{m}^2$, which is still acceptable. This version of the fall is plausible.

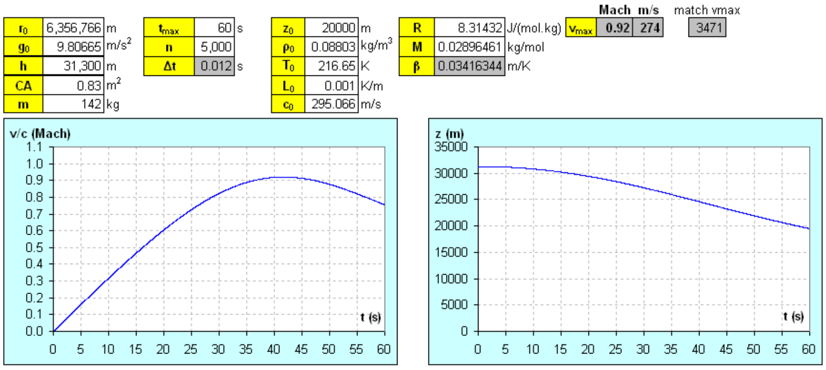

Figure 2. Speed and altitude of a person falling in the stratosphere:
h = 31,300 m, CA = 0.83 m^2, m = 142 kg, $v_{\max}$ = 274 m/s = Mach 0.92

It is clear from Fig. 3a that reaching maximum speed of 319 m/s (Mach 1.08) is possible if CA = 0.46 m^2. If $C \sim 1$, then $A = 0.46$ m^2, if $C \sim 1.2$, then A = 0.38 m^2 and if $C \sim 1.3$, then A = 0.35 m^2. The values of A are too small. It is impossible that Kittinger could reach this speed.

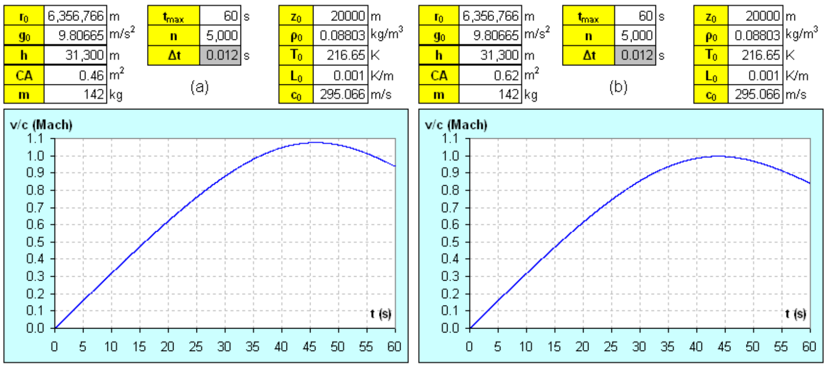

Figure 3. Speed and altitude of a person falling in the stratosphere: h = 31,300 m, m = 142 kg,
(a) CA = 0.46 m^2, $v_{\max}$ = 319 m/s = Mach 1.08, (b) CA = 0.62 m^2, $v_{\max}$ = 296 m/s = Mach 1

Fig. 3b shows that sonic speed (Mach 1) could only be reached if CA = 0.62 m^2. If $C \sim 1$, then A = 0.62 m^2, if $C \sim 1.2$, then A = 0.52 m^2 and if $C \sim 1.3$, then A = 0.48 m^2. Also these values of A are too small for the Kittinger's way of fall.

Suppose Kittinger would fall head-to-earth, arms and legs straiten back, and with well-shaped load. It holds that $C < 1$ for such a system at subsonic speed, so $C \sim 1$ is possible at sonic speed. The corresponding area A = 0.62 m^2 is acceptable (Fig. 3b). If m = 100 kg, then the model gives CA = 0.43 m^2; if $C \sim 1$ then A = 0.43 m^2, which is still acceptable. Thus, reaching sonic speed is possible. The question is whether the jumper would survive. Kittinger had serious breathing difficulties from 27,400 m to 21,300 m because of the helmet that was pressing against his throat. Fig. 2, right side, shows that it was from t = 29 s to 57 s. Fig. 2, left side, shows that Kittinger was just in the transonic range, that is, above Mach 0.8. Then, "Parts of your body may be going supersonic while others aren't, causing flutter waves pulling back and forth … that knocks him out of control" (Tierney, 2010). This turbulence caused tragic plane crashes when breaking the sound barrier at the end of forties. The problems with the helmet could not have been caused by anything else.

Fig. 1 shows a hypothetical Kittinger's fall from 11 km where the troposphere ends. Passenger airplanes cruise at this altitude. The maximum speed is 88 m/s, which is just Mach 0.29. To reach 100 m/s, it has to hold that CA = 0.62 m^2. If m = 100 kg, then the model gives CA = 0.44 m^2.

Conclusion

The project shows the great possibilities that spreadsheet offers for studying school subjects. The facts in section 2 are additional to physics curriculum, Eqs. (1) – (3) show using higher functions in practice. Calculating the impact speed is an example of getting a value that is not in the cells by interpolation using the values returned by functions MATCH a OFFSET. They are important for those who will use Excel for modelling in science, engineering, business, etc. The analysis is an example of scientific argumentation to find the solution. The result is: A person falling in the air can reach supersonic speed if he falls in the stratosphere from the altitude of about 32 km head-to-earth. Surviving is doubtful. In the troposphere, the maximum speed is about 100 m/s.

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Teacher Assistance Tools for the Constructionist Classroom

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Abstract
The work presented in this demonstration is the product of the interdisciplinary MiGEn project, which aimed at designing and developing an intelligent, exploratory environment to support 11–14-year-old students in their learning of algebraic generalisation, but also providing tools to support teachers in its use in the classroom. We will present these tools, which are designed to assist teachers in monitoring students' activities and progress in lessons, and discuss their value for a constructionist environment.

Keywords
microworlds, algebraic generalisation, teacher assistance tools

Introduction

Research in students' learning with microworlds has long highlighted the indispensable role of the teacher as a 'competent guide' (Leron, 1985), a 'facilitator' (Hoyles, Sutherland, 1989), or 'orchestrator' (Trouche, 2004; Hoyles et al., 2004) of both well-defined investigations (Kynigos, 1992) and goal-oriented exploration, which aligns with a learning agenda (Noss & Hoyles, 1996). However, in practice, this role is difficult to achieve in a typical classroom and we believe this contributes to the lack of adoption of constructionist technologies. In the efforts, therefore, of the MiGen project (http://www.migen.org) to support teachers in employing a microworld for algebraic generalisation in the classroom, we designed and developed a suite of visualisation and notification tools, which we refer to as Teacher Assistance (TA) Tools. These inform teachers of individual students' progress, their history of actions, and their current working status. Such information is of real value to teachers who can then make informed decisions to support students and orchestrate the classroom activities.

In this paper, we first provide a brief description of the algebraic microworld that the TA Tools are designed to work with. We then give a detailed explanation of the tools, and we finally share some conclusions regarding our vision of supporting teachers in the constructionist classroom through tools that assist them in visualising students' progress and accomplishment of specific learning goals as students are working on their constructions.

eXpresser: A microworld for algebraic generalisation

We have designed and built a pedagogical and technical environment for improving 11-14 year-old students' learning of generalisation. The major components of the system are the microworld, the Intelligent Support component and the Teacher Assistance Tools. As well as building the technological system we have designed a set of activity sequences.

In the eXpresser microworld, students construct figural patterns by expressing the structure of the patterns by means of repeated building blocks of square tiles, and also articulating the rules that underpin the calculation of the number of tiles in the patterns. A typical activity will ask the student to reproduce a dynamic model presented in a window that appears on the side of the activity screen. Figure 2 shows such a model where a row of red tiles is surrounded by grey tiles.

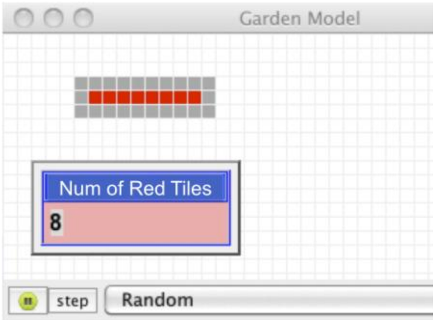


Figure 1. A model for a row of red tiles surrounded by grey tiles. Students are asked to construct a general model and find the general rule for the number of tiles surrounding the red tiles.

Students are asked to construct a model that works for *any number* of red tiles, and find a rule for the total number of tiles surrounding the red tiles. They can test the generality of their model and rule by *animating the model:* that is, by letting the computer change the number of red tiles at random and ensuring that their model remains coloured and therefore is impervious to changes in the values of the variables. To scaffold students' interaction in such an open and exploratory environment activities we provide a constant reminder of their tasks and goals by breaking down the task into goals. Examples include (1) Use pattern(s) to construct the model, (2) Make sure "My Model" is always coloured, (3) Check that the "Computer Model" animates without messing up, and (4) Make sure the "Computer Model" is always coloured. Underlying these surface goal, the main objective is to enhance students algebraic ways of thinkings (Mavrikis et. al, to appear).

Even though the system includes an Intelligent Support component that takes as input information from the microworld as students undertake tasks and enables the provision of real-time and adaptive feedback to students, we recognised the necessity of assisting the teacher in offering the best possible support to their students when using the microworld in the classroom.

The teacher assistance tools

When using computers in lessons, it is rather difficult for a teacher to observe what every student is working on and whether they are working on the task set or not. Especially with constructionist environments, where students construct models in a variety of ways, a teacher cannot be sure of students' prior actions by simply looking at their screens from time to time. Therefore making an informed decision and providing appropriate feedback can be difficult. Our main goal for developing the teacher assistance tools was to increase the teacher's awareness of their students' attainment and overall progress in lessons. There are currently 4 tools: Student Tracking Tool, Class Dynamics Tool, Goal Achievement Tool and Grouping Tool. The Student Tracking tool shows a timeline of significant events (termed indicators) from each student's interaction with the microworld. Although it can be used during a classroom interaction, the level of detail that it provides means that it mainly fits the purpose of post-hoc analysis of a classroom interaction, either by researchers or teachers. Since the focus of this paper is on the way teachers can be supported in the classroom, we will discuss in more detail the other 3 tools. For more details on the Student Tracking tool the reader is referred to Gutierrez-Santos et al. (in press).

Classroom Dynamics Tool

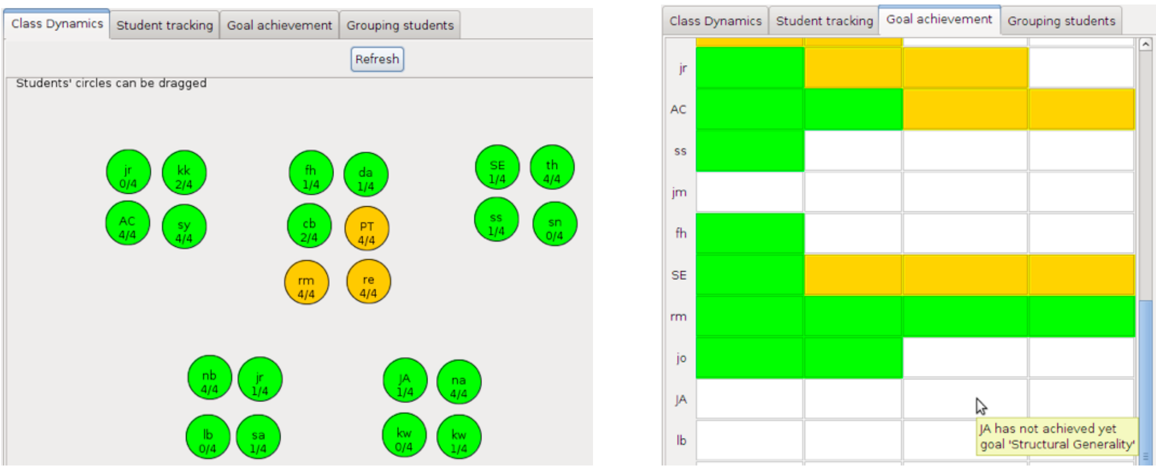
The Classroom Dynamics Tool (CDT) provides information about the state of the classroom to help the teacher decide at a quick glance where to focus their attention. It shows students as circles on a canvas containing their initials to identify them. A teacher can place the circles according to the students' spatial distribution in the class in order to make easy the identification of the students faster (see Figure 2). The circles are coloured to indicate the status of the students. In more detail, students shown in green are interacting with the microworld. Students shown in amber are inactive. This means that they have not interacted with the microworld for a certain time (by default, five minutes). Unless this is expected for some reason (e.g. sometimes the teacher interrupts the session to address the class and explain some common misunderstanding) it usually means that students are distracted: they may be talking to a peer or, as we have observed in some schools, playing games in their web-browser. Students shown in red are waiting for the teacher to help them. This means that students have requested help from the system in a situation where the intelligent support provided by the system cannot help the student any further. At this point, the student appears in red in the CDT to attract the attention of the teacher. Hovering over a student's circle in the CDT with the cursor shows additional information about the student: their full name and their status.

Goal Achievement Tool

The Goal Achievement Tool (GAT) provides information about completion of task goals, providing teachers with an overview of the progress of the class with respect to their plan for the lesson (see Figure 3). The microworld is equipped with the ability to design specific tasks the accomplishment of which is monitored by the intelligent components of the system (see details of the design of the intelligent aspects of the microworld in Mavrikis et al., in press).

Grouping Tool

The Grouping Tool (GT) supports the teacher in managing collaborative activities, by automating the pairing of students based on students' prior constructions. To generate fruitful discussions, students with different constructions and dissimilar models should be grouped. During a lesson, identifying appropriate pairs is time-consuming and the teacher cannot dedicate more than a few minutes to this activity. Accomplishing it would require the teacher to investigate every student's construction, model and rule to identify the dissimilar ones and then pair the students, taking also into account factors such as students' attainment level. The GT is designed to aid the teacher in this task by automatically generating an initial set of pairings. These are shown visually to the teacher, who can then confirm or change each pairing. As shown in Figure 4, in the GT students are represented by their initials within a circle, and the degree of similarity between pairs of constructions is represented by a small green rectangle for low similarity; medium-sized yellow rectangle for moderate similarity; or large red rectangle for high similarity. The teacher can select students' circles and 'drag' them into different groups to change the pairings suggested by the system and take into account, for example, factors that are beyond the system's knowledge, such as students' interpersonal relationships.



Figures 2 and 3. Classroom Dynamics Tool and Goals Achievement Tool.

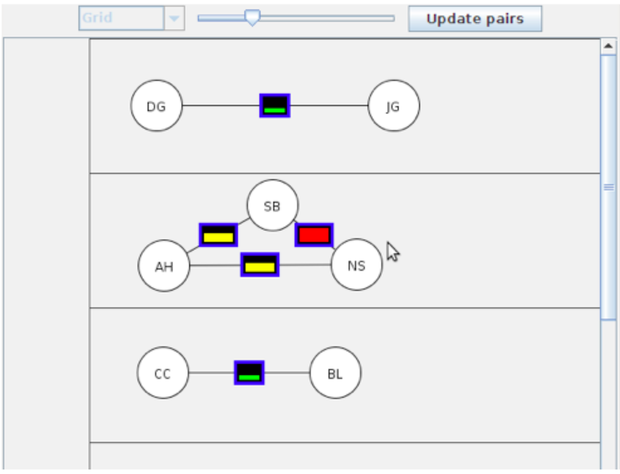


Figure 4. Grouping Tool.

Discussion and Future Work

In order to design the teacher assistance (TA) tools, we have collaborated with a number of educators and teachers in secondary schools in the UK. Initial prototypes of the TA Tools were designed based on their input. We then followed an iterative design process in order to provide the requirements that teachers identified as crucial.

Over the course of the project, we conducted several one-to-one, small-scale, and whole-classroom trials with our system in a number of secondary schools in the UK with 11-14-year-old learners. We observed the use of the TA tools by the teachers, especially their reactions and methods of incorporating the system into their lessons. It was evident that once our teacher collaborators used the tools in their classrooms, they were able to give us more informed feedback and influence subsequent development. We have also conducted evaluations of the TA tools with the help of trainee teachers, using secondary data we collected from the school trials.

Based on teachers' feedback, we identified that providing a tablet PC where the TA tools were installed would help the teacher to move around the class rather than returning to their desk to view the tools. In lessons, we found that teachers were consulting mainly the Classroom Dynamics Tool on their tablet PC. With this tool, they decided early in the lesson to move the circles representing each student to reflect the seating plan of their class. As most teachers stated afterwards, this helped them use the tool more effectively and locate quickly which students needed help at any given moment. As soon as a circle turned red, the teacher clicked on the circle to investigate the student's current construction and prepare their intervention. In one trial, the teacher decided to also display the Classroom Dynamics Tool on the Interactive Whiteboard. This encouraged students to stay on task, as they were aware of other students being able to view their progress. It also freed the teacher from having to hold the tablet PC.

Teachers also regularly viewed the Goals Achievement Tool during the lesson, to view students' overall progress in terms of task completion. They found this tool very useful when deciding which students to help based on the goals they have achieved, but also when designing subsequent lessosn. The next task was usually a collaborative activity (see Geraniou et al. 2011) and before asking students to pair up and start the task, teachers opened the Grouping Tool. This analysed the students' submitted models and rules and suggested possible pairings, based on the degree of dissimilarity of students' constructions. By quickly examining the suggested pairs and after ensuring that other parameters, such as students' interpersonal relationships and attainment levels would not hinder their collaboration students were grouped. Teachers recognised that the greatest value of the tool was in quickly generate pairs and being able to ask students to start the collaboration activity almost immediately after finishing individual work.

Our future plans involve improving the TA tools and investigating how they could be adapted to support teachers using other constructionist environments. We are in the process of sharing these tools with more teachers and disseminating our results to a wider community. Also, we are interested in continuing our research to investigate further how such support towards the teacher influences constructionist learning in the classroom.

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Acting like a Turtle: A NetLogo Kinect Extension

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Abstract

The Microsoft Kinect 3-d camera offers new and exciting possibilities for constructionist learning. This Constructionist Media Demonstration presents a NetLogo extension that enables learners to use the Kinect as an input device to NetLogo models. We have so far constructed three learning experiences, designed using NetLogo and the Kinect. At the end of this paper, we discuss some theoretical implications for using Natural Interfaces for constructionist learning and discuss the challenges that it poses to us as designers of constructionist learning environments.

Keywords

NetLogo, agent based modelling, constructionism, kinect, embodied learning

Introduction

NetLogo (Wilensky, 1999) is an agent-based modelling language with a long history of facilitating constructionist learning in sciences (e.g. Levy & Wilensky, 2009; Sengupta & Wilensky, 2009; Wilensky, 2003; Wilensky & Reisman, 2006). The NetLogo Extensions API, first released in 2004, allows users to expand on the NetLogo programming language by coding new NetLogo primitives and data structures in Java, sometimes introducing new technologies as in- or output to NetLogo models. An example of the latter is Blikstein and Wilensky's (2007) work on bifocal modelling, in which they used the NetLogo Extensions API to connect GoGo Boards (Sipitakiat, Blikstein, & Cavallo, 2004) to NetLogo models. The purpose of this short paper is to demonstrate how we used the NetLogo Extensions API to combine the Kinect and NetLogo, and to provide a few examples of what we think are fun and interesting possibilities for learning and expression using this powerful new technology.

Model 1: Stop thinking like a turtle and act like one!

When working with kids and geometry, Papert (1982) encouraged his learners to "think like a turtle" and use the Turtle as a transitional object. Eisenberg (2003) later argued that it is in fact the turtle-plus-language system that constitutes the transitional object. With the Kinect, we expand on this view to a 'turtle-plus-language-plus-body system'. This NetLogo/Kinect model builds on Papert's body syntonic approach by letting users draw shapes using their bodies, and saving them in NetLogo. A 'drawing turtle' is first created, and the learner can raise their arm to ask the turtle to start recording what they do. The learner can then walk around the room in the shape they wish to draw, while NetLogo records their movement. Finally, the learner can raise their arm to ask the turtle to stop recording, give their new shape a name, and save it (See Figure 1).

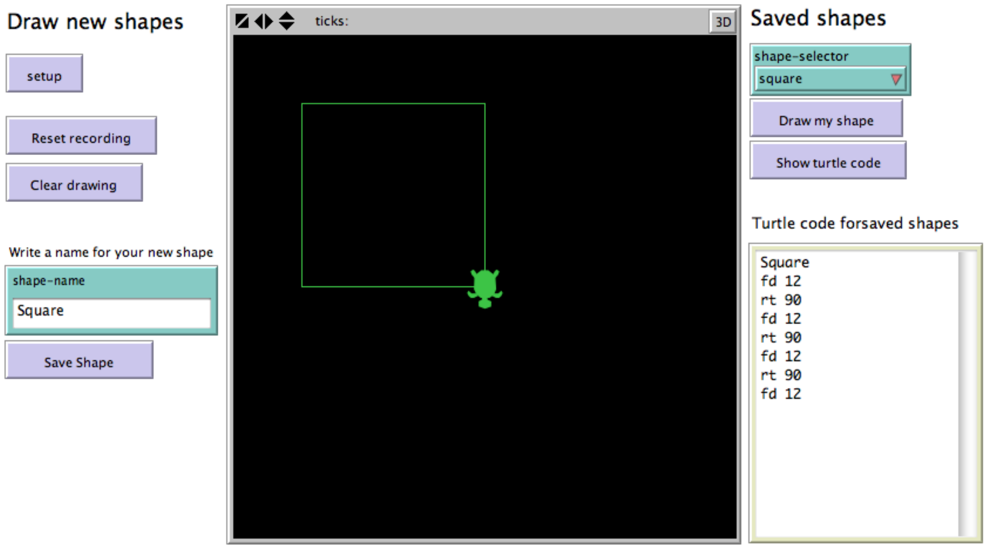

Figure 1. Kinect Turtle Geometry: Interface

Learners can now ask the turtle to draw the shape they moved in, or they can ask the turtle to show the NetLogo turtle code for this movement. Learners can construct a collection of shape-turtles that each "remember" the shape in which the learner moved. Classic Logo shapes such as a circle or a square can thus be bodily constructed; and later combined into more complex structures.

By allowing learners to shift between multiple representations of movement, shapes, and geometry; by using their bodies to 'write' turtle code that they can later work with *as* code; and ultimately to both *think* and *act* as turtles, it is our hope that leaners can construct more embodied understandings of geometry.

Model 2: To flock or not to flock

Complex Systems theorists (Johnson, 2001; Wilensky, 2001) have argued that some of nature's complex patterns arise out of interactions between simple behaviours of individual agents. One of our favourite models illustrating this principle is the NetLogo *Flocking* model (Wilensky 1998). However, while the surprising and beautiful patterns that emerge from these simple interactions demonstrate the power of multi-agent modelling. However, using the model, learners can explore a range of patterns and experiment with variations of the generating rules, but they are not able to participate bodily in the formation, breaking, and sustaining of these patterns.

We extended the 3-D version of the NetLogo model *Flocking* (See figure 2). By allowing a user to steer one bird with their body (See Figure 3), learners can now not only modify and change the behaviour of the individual birds, but also experience how their steering of one bird can interact with the system as a whole.

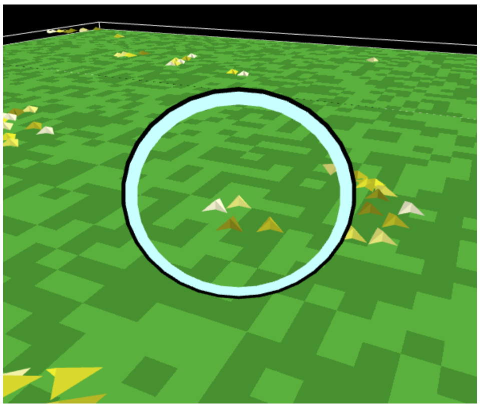

Figure 2. The learner can control a bird with their body, and attempt to "become one" with the flock, or try to disrupt the emergent formations by breaking out of it.

By being able to interact with the complex system by directly manipulating just one bird, we hope that learners gain a more embodied way of experiencing and engaging with flocking behaviour and with emergent complexity.

Model 3: Mutual Attraction?

DiSessa's (1993) research on children's conceptions of tidal bulges highlights two important points: First, that children (and, may we add, adults!) struggle with the concept of the two tidal bulges. Second, that explicating and becoming aware of one's own conceptions about the forces between Earth, water, and the Moon is a necessary first step towards making sense of this complex phenomenon.

To address this, we designed a 2-learner model. In the model, one learner takes on the role of Earth, and the other the role of the Moon. Each learner controls their celestial body by walking around the room. The model automatically simulates gravitation between Earth, the Moon, and the water on Earth, creating one of the two tidal bulges, the one that is more widely understood – the one facing the Moon.

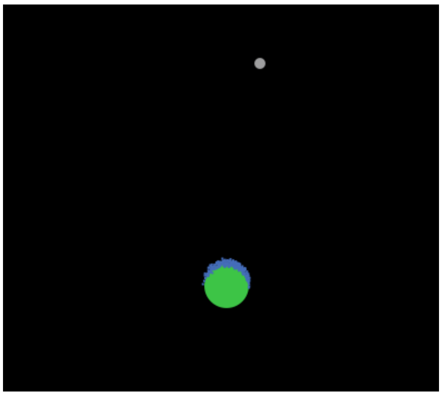

Figure 3. The tidal bulge facing the Moon is created by gravitational forces between the water turtles and the moon turtle in the top of the image.

The two learners must now find out how to move relative to each other so that they can recreate a correct representation of both tidal bulges. Only by moving around each other, simulating the centripetal power that creates the tidal bulge on the opposite side of the Moon, can learners successfully do so. Our goal is that through the coordination, the learners will engage in conversation that helps them articulate their own conceptions, and engage with each other's conceptions in fruitful ways.

Conclusion

In this brief paper we described three examples of models that we believe have he potential to be engaging and meaningful learning experiences, utilizing the Kinect extension for NetLogo. Ultimately the usefulness to education of "natural Interfaces" like the Kinect is of course an empirical question. We plan to study these activities with a variety of learners and analyse both engagement and learning.

We faced some new, interesting, and challenging questions as we were designing the Kinect extension. As designers of constructionist learning environments, our ambition is to develop tools-to-think-with. Part of this work, then, consists of creating external representations of knowledge and thinking with which people can construct their personally meaningful objects. Particularly, when we design learning environments that include programming, we must pay attention to how the design of our programming primitives affects their thinking-with*ness*. But how do we think with our bodies? If we stand up and raise a hand, most people would agree that our hand is now "above" our head. But what if we lie down on our back? Would a hand "above" our head float in front of us, its *aboveness* assessed by its larger distance from the core of the Earth? Or would we raise our hand like we did when we stand up, assessing the aboveness by a feeling of embodiment that tells us that "up" runs from our feet, through our spine and neck and into our heads? What is "up", anyway?

These questions, although maybe silly on the surface, are important to understanding how to design programming primitives for people to think with. Part of our work over the coming years will therefore be focused on articulating a *constructionist vocabulary for natural Interfaces*.

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Modeling Commons

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Abstract (style: Abstract title)

Our research project, the "Modeling Commons," is designed to make the agent-based NetLogo modeling environment (Wilensky, 1999) not only an effective tool for creating models, but also for sharing them with others and collaborating during the modeling process. It is also meant to help modelers organize their work into "families" of related models. In this demonstration of constructionist media, we will show the basic features of the Modeling Commons, a Web application that allows NetLogo users to share models with one another, collaboratively write and edit models, discuss models, and categorize models with social tags. We point to the ways in which we have designed and implemented the Modeling Commons as a constructionist environment, from the implementation of a version-control system accessible to non-programmers, to making questions prominent and visible to all users, to the permission system that lets modelers keep their work private until they consider it ready for public consumption. We then describe planned future features for the Modeling Commons, including support for NetLogo extensions, a Wiki for each model, and cross-model discussions.

Keywords (style: Keywords)

Constructionism, Collaboration, Modeling, Social interactions, CSCL, World Wide Web, NetLogo

Introduction

Modeling plays an important role in many fields of research, including science, mathematics, engineering, and (most recently) social science (Morrison & Morgan, 1999; Axelrod, 2005; Epstein, 2008). Models provide a bridge between theory and practice, offering a form of reified theory that can be manipulated, prodded, and poked in various ways, to test its responses to various inputs and scenarios. While there are different types of models, ranging from equations to physical mock-ups, modern-day models are often built in software, in the form of a computer-based simulation (Jonassen, 2006).

One technique for creating software simulations is known as "agent-based modeling." In such a system, the modeler creates software entities, known as "agents," and then gives those agents rules to follow. Such rules can describe how they move around the virtual world and how to interact with other agents they might encounter. For example, to model the spread of disease in a population, each agent might represent a person; an infected person would pass the disease onto another based on a number of pre-programmed criteria, such as the distance between the two agents, the health of each agent, and a random factor.

A popular environment for creating agent-based models is NetLogo, which has long supported constructionist learning (Wilensky, 1999). NetLogo's users range from middle-school students through university researchers. The software comes with several-hundred sample models, on subjects ranging from the aforementioned spread of disease in a population, to the "Monty Hall" problem, to the way in which leaves change color in the autumn, to the way in which people separate when participating in an exercise class. NetLogo is exploratory and constructionist by design, encouraging users to create and run their own models, learning about a particular subject domain in the process.

A growing body of theory and evidence point to the importance of social interactions when among learners (Vygotsky, 1978; Lave & Wenger, 1991). Papert himself, when he defined constructionism (Papert, 1980), indicated that it involves not only building, but also sharing with others.

From interviews with NetLogo users of varying skill levels, we know that NetLogo models are often built through a process of collaboration, sometimes with other modelers and at other times with domain experts. However, NetLogo lacks any built-in tools for facilitating such "genuine interdependence" (Salomon, 1992). Modelers have thus created their own tools and processes for sharing models with one another, gathering feedback from peers, and including multiple people in the modeling process.

Our research project, the Modeling Commons, has two separate but related goals: First, to facilitate a variety of types of interactions among modelers, to offer them a platform that allows them to cooperate, collaborate, and share with one another. A second goal is to better understand the ways in which modelers communicate and interact. By interviewing modelers before and during their use of the Modeling Commons, and by examining the logfiles generated from its use, we have already gained perspective into the ways in which people work together, and are using such information to improve the experience and the modeling environment.

While the Modeling Commons has been under development for several years, it was announced and open to the public in early 2012. Several hundred new users have already registered, and several dozen new models have been shared.

For the Constructionism 2012 conference, we would like to demonstrate the Modeling Commons, reviewing its features, including a number of the design considerations that went into its creation not only as a tool for Web-based collaboration, but as an environment in the constructionist tradition. We hope that by sharing the Modeling Commons with other researchers, we will help to improve the development not only of technologies among constructionists — who need no convincing about the benefits that such technologies can provide — but of technologies that encourage a variety of social interactions.

Features of the Modeling Commons

At its core, the Modeling Commons lets people take an existing NetLogo model, written on their own computer, and upload it. Each uploaded model gets its own, unique URL and page within the Modeling Commons. After just this initial upload, going to that URL provides users with the ability to view the model's preview image (assuming that one was uploaded), run the model in the Web browser (as a Java applet), view the model's procedure definitions, and read its "info" tab, describing the model to potential users and collaborators.

We should note that the Modeling Commons is an attempt to provide a solution to multiple communities, each with its own needs. By default, uploaded models can be viewed and modified by any registered member of the Modeling Commons. (Registration is free, and requires that the user fill out a simple, short form describing themselves.) However, we know that for some users — particularly in educational settings — users will want to keep their work private, either just to themselves or to other members of a group. For this reason, the Modeling Commons allows model authors to permissions on a model, and to define a group of people who are allowed to view and/or modify it. The default permissions are currently quite open, allowing anyone on the Internet to view a model, and also allowing any registered Modeling Commons user to change a model.

Even if someone uploads a new version of a model that breaks it, or substantially changes its behavior, it is possible to go back one version with a few clicks of the mouse: We keep the entire history of every model, such that it is always possible to revert to a previous version. This "undo" facility on models is meant to give modelers confidence, allowing them to make mistakes, debug them, and learn more about their model in the process.

In many cases, we have found that modelers wish to create multiple variations of a model, either because they are exploring multiple, related simulations or because they had varying levels of complexity. In either event, our "model family" functionality is appropriate; when you upload a new model version, you can specify that it should replace the existing version, or that it should be a new model, but with a parent. Over time, we hope to see many families of related models, looking at topics from different angles. For collections of models that are related by topic, but which do not have an obvious parent-child relationship, we also offer "projects," a looser and less hierarchical association than the family relationship.

The Modeling Commons also offers a forum for each model, allowing people to exchange ideas and/or questions about the model, the domain explored by the model, or NetLogo coding. Another form of communication is the "social tag," allowing any Modeling Commons user to add one or more textual descriptions to a tag. We hope that over time, users will create a "folksonomy" for models, making it possible to find all of a models on a particular topic.

While the Modeling Commons offers modelers a variety of functions, we have learned through our testing period and since the launch that additional features are necessary: We intend to support NetLogo extensions and external files, both of which are in increasingly common use. We have also found, in our research, that providing additional support for non-programmers is important, and are thus planning to provide a Wiki for each model, as an open-ended notebook, communication device, and scratchpad for modelers. Finally, we have begun to see cracks in our model-centric design, and are planning to introduce features that will make it possible to have a discussion extend over multiple models in a family or project, rather than on only one individual model.

Conclusion

The Modeling Commons is a constructionist environment for users of a constructionist modeling tool (i.e., NetLogo). Whereas the focus behind NetLogo is the creation of new models, the Modeling Commons exists to share existing models, and to encourage people to edit, improve, and communicate with others during the modeling process. We believe that our work on the Modeling Commons will provide useful ideas for others interested in creating online environments, particularly from within the constructionist role.

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Dialogs with Prometheus: Intelligent support for teaching mathematics

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Abstract

Dialogs with Prometheus includes an intelligent support based on natural language dialogues between the system and the user in order to feed the latter's ideas and actions back into a specific microworld. With this tool it is possible to simultaneously display on a computer screen a chat window and a microworld window, both of which are dynamically hot-linked to each other. The complex interaction between the learner and the two windows may be applied in several specialized ways like using the microworld window only as visual feedback to the chat, or by providing the learner with text feedback relevant to what he/she is doing in the microworld. For the prototypes developed so far, we have resorted to the experience of research carried out using a variety of digital learning environments. The latter, with the intention to recreate the constructionist character of actions and related learning activities that enable those settings.

Keywords

Feedback, intelligent system, dialogue window in a microworld

Feedback in digital learning environments

More than three decades of experience in researching the potential of digital environments as a favorable means for learning and teaching mathematics and sciences has shown that in order for that potential to be effective significant and sustained pedagogical support from the teacher is necessary. Yet this requirement is very difficult to meet because use of digital media fosters an exploratory attitude among students, which leads to displaying a great diversity of approaches and strategies for problem resolution or for other activities in the classroom, which in turn makes it almost impossible to have timely and specific feedback for all cases. This limitation represents one of the greatest obstacles encountered when it was time to implement models for use of digital technologies to teach mathematics and sciences, both in the classroom setting and in distance education systems (Sinclair, Arzarello, et al, 2010).

Although the majority of computer programs that are the basis for the so-called microworlds encompass, in their very design, feedback modes to help students comprehend concepts, methods or properties in mathematics or sciences, in and of itself that feedback does not always respond to the specific needs of the students at given times. This problem has been approached in recent research, as is the case of the MiGen Project of the London Knowledge Lab (http://www.lkl.ac.uk) that developed an intelligent support system in order to incorporate it into the microworld *eXpresser* –the latter was designed to help students with mathematics generalization processes. Inspired by robotics methodologies and by adaptive systems, the MiGen Project proposes a layered approach for developing an environment in which there is a coexistence of a microworld and an intelligent system for feedback, collaboration and assessment of that same microworld (Gutiérrez-Santos, Mavrikis, & Magoulas, in press).

Dialogs with Prometheus

On the other hand, the main trait of the *Dialogs with Prometheus* tool –presented here- is that it uses intelligent support based on natural language dialogues between the system and the user in order to suggest and feed the latter's ideas and actions back into a specific microworld. *Dialogs with Prometheus* is developed with the author system *Descartes* [1] (http://recursostic.educacion.es/descartes/web/), with which it is possible to simultaneously display on a computer screen (or other digital artifact screen) an *intelligent dialogue* window and a window with a microworld or a digital interactive learning environment, both of which are dynamically hot-linked to each other. By using this tool the students can work in the micro-world on specific tasks and carry on a dialogue with the system, based on suggestions and questions raised by the latter, so that the feedback that they receive actually responds to their specific needs at a given point in their actions within a learning activity. In technological terms, the operation of both interconnected windows can be described in the following manner:

The tool *Dialogs with Prometheus* consists of two modules: CHM and MWM. CHM stands for CHat Module and MWM for MicroWorld Module. Both CHM and MWM have well defined functional behaviours and are designed to work independently of each other. However they communicate through a thin protocol consisting of only two parameters Q and A, which represent the state of CHM. Specifically, Q represents the Question or command being proposed by CHM to the learner, and A is the Answer that the learner has given (if any) to the CHM. The CHM informs the MWM of this situation and reacts accordingly by modifying its own state to fit the needs of that particular chat situation. But the MWM may receive input from the learner too, so it can decide to request the CHM to change its state and pose a different Q.

This complex interaction between the learner and the two modules may be applied in several specialized simpler ways like using the MWM only as visual feedback to the chat, or by providing the learner with text feedback relevant to what he/she is doing in the MWM. Of course, dialogs that take advantage of all different forms of communication provide a more complete educational experience. All this is miles away from mostly linearly conceived computer aided instruction. However, a word of warning is in order, *Dialogs with Prometheus* is not a simple tool for the developer of interactive learning resources. It takes a lot of effort to produce one of them, mostly because creating dialogs is, in itself, a very difficult task. We are working in trying to understand better the inner structure of dialogs as logical constructs and also in learning how to understand written responses to concrete questions and how to instruct the computer to react. There is still a lot of research to be done in this aspect. On the other hand, the creation of MWMs does not represent a problem thanks to the tool *Descartes* which is perfectly suited to create almost any MWM one could need.

Intelligent dialogues and teaching modes

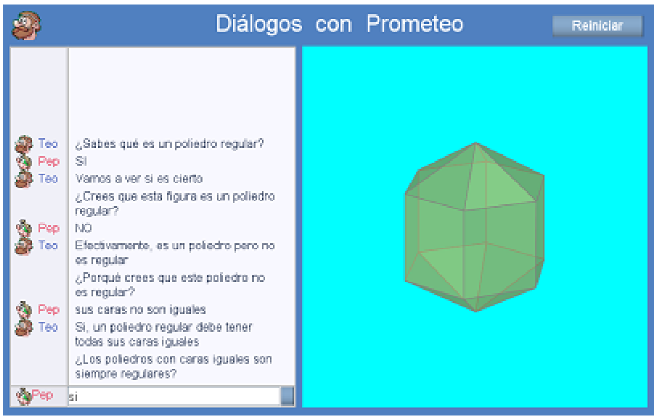
In educational terms the tool was conceived to be used both in individualized feedback mode and to provide feedback on group or collaborative task activities. Its design also allows for in-class and remote education applications. In the latter respect, one should note that *Dialogs with Prometheus* work always online, and are being adapted to work on tablets and mobile phones. The way this is being done is by creating a JavaScript interpreter, taking advantage of the HTML-5 specifications, of the Descartes Runtime that was originally programmed in Java. Most of the *Descartes* functionality is already working in this new interpreter. So, *Dialogs with Prometheus* will be available very soon for tablets and mobile phones.

Since the nature of the actions that can be undertaken in this environment depend on the design of the microworld included in a given dialogue, so far, for our developments we have resorted to the outcomes from research carried out with a variety of digital learning environments, such as spreadsheets, dynamic geometry programs and Logo. Hence the intention is to recreate in the microworld window the constructionist character of actions that enable those settings. On the other hand, such a constructionist character can be enhanced due to the additional feedback that takes place in the chat window through an intelligent support, which intervenes in key episodes of the user's reasoning during a learning activity.

Types and prototypes of Dialogs with Prometheus

To date the following types of dialogues have been developed at the prototype level: 1) Learning and clarifying essential properties of geometric figures and concepts. 2) Exploring and building parameterized models of physical world phenomena. The phenomena are expressed and explored by using variation tables (spreadsheet-like), graphic representations and simulations of the phenomenon in question. 3) Intuitive exploration of discrete mathematics theorems. 4) Giving instructions to the microworld. 5) To develop other dialogues (abstract dialogue template).

The prototypes developed, pursuant to the foregoing dialogue types are (http://arquimedes.matem.unam.mx/Dialogos/): *Regular polyhedrons*: belongs to type 1 and its objective is to help the user gain a clear idea of the essential properties of polyhedrons. A fragment of dialogue is reproduced in the figure below, and depending on the user's response to a question posed by the system, the latter gives the user feedback either confirming the answer or by giving a counter-example (Figure 1). *The square*: is type 1 and its goal is to establish one single essential property of the square. Conceived as a generic example of this type of dialogue, in which the intention is for the user to discover for him/herself the essential traits of the concepts studied (Figure 2). *Environmental pollution*: belongs to type 2 and it consists of presenting a parameter-based model of the phenomenon of a lake polluted by factory waste, and for which the user explores the phenomenon by way of varying the parameters, such as the annual rate of waste (amount of pollutant flowing into the lake) and the crossing river outflow (the river crosses the lake). *Molecular diffusion*: belongs to type 2 and here the user is asked to numerically, algebraically and graphically explore a simplified version of the phenomenon of molecular diffusion in a cell with the help of a simulation window (Figure 3). *Exponential population growth*: type 2 and here the user studies population growth and the factors that modulate it due to competition or overpopulation. Several exponential-type models are explored. *Non-crossing matchings*: belongs to type 3 and with it users can create matchings (join two points using line segments) between a set of n red points and a set of n blue points. The user can intuitively describe, by way of questions posed by the system, the general result that it is always possible to find a non-crossing matching between two such sets of points (in which any red point is joined to a blue one and vice versa, without there being segments that cross each other) (Kaneko & Kano, 2003). *Logo*: type 4 and in which the user directs the movements of a turtle by giving instructions. *An abstract dialogue*: belongs to type 5 and it serves as a template to formulate other dialogues. It is made up of two files that are *Descartes* scenes: diálogo.html and micromundo.html.



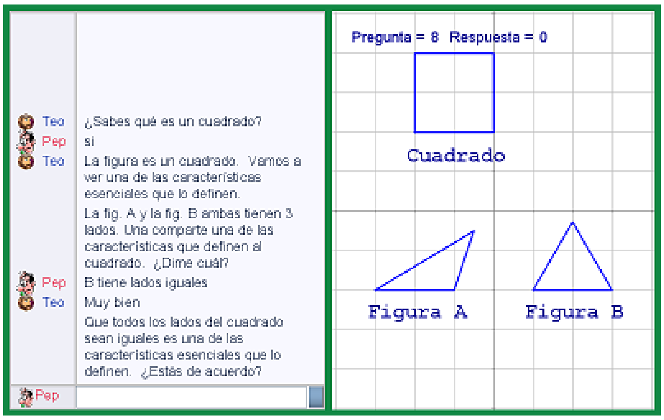


Figure1. The Polyhedron

Figure 2. The Square

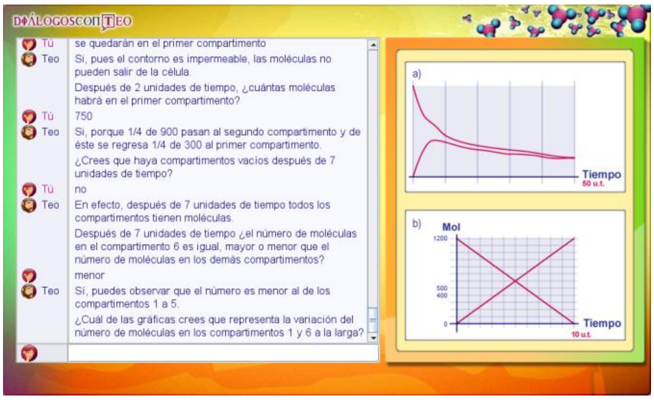


Figure 3. Diffusion in a cell.

Feedback in Dialogs with Prometheus

Intelligent feedback based on empirical studies

Design of the parameter-based modeling activities and of the specific feedback for each one is based on the findings of the testing of this type of activity with in-class students in a science classroom. The experiment, undertaken within the framework of the Anglo-Mexican Project “The role of spreadsheets within the school-based mathematical practices in sciences” [2] made it possible to identify critical modeling moments for each particular activity, moments such as prediction, model validation and model generalization moments (Molyneux, Rojano et al, 1999). Thus taking those findings into consideration, the feedback from the *intelligent* system focuses on helping the students to: check their predictions (often intuitively formulated); check their answers; and to validate and generalize their models and methods.

Intelligent Feedback based on Dialog Structure and Logical, Linguistic and Semiotic Analysis

As mentioned above, two of the most difficult aspects of Dialog development are 1) the functional structure of educational dialogs and 2) the recognition of answer patterns from actual written text. These two subjects are being investigated by a team of collaborators. The first aspect is required to organize and facilitate the development of actual dialogs. We have a data structure defined which allows their creation and development, but there is a lot to be learned yet about how dialogs must be structured in order that they become useful learning tools. As for answer pattern recognition, a logical structure is being developed to define and specify answer patters, and a web service is already well under construction, which allows the chat module to recognize when a written text matches an expected answer pattern. This of course is vital for *Dialogs with Prometheus* to work properly, but it still requires much research and development.

Final remarks

In addition to the aspects mentioned above that are still under development, an empirical study has also begun with tertiary education students in order to test the modelling dialogues (a project funded by Conacyt, Mexico, ref. no. 168620). In the study the structure of the dialogue component and a logical linguistic and semiotic analysis will be brought together with the experience of the actual use of the dialogues so as to have the elements needed to improve upon the tool within the framework of a resourceful methodology.

Notes

[1] Descartes is an open source Authoring Tool for interactive Mathematics resources developed by the Spanish Ministry of Education, with the participation since 2009 of Instituto de Matemáticas, UNAM, and LITE, a project of ICyTDF, the Science and Technology Institute of the Mexico City Goverment.

[2] Anglo-Mexican Project developed in collaboration with the Institute of Education of the University of London and the Department of Mathematics Education of Cinvestav, Mexico, and funded by the Spencer Foundation of Chicago, Ill (Grant No. B-1493).

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Evolution in Blocks: Building Models of Evolution using Blocks

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Abstract

Evolution undergirds the domain of biological sciences. Despite its centrality to the biological sciences, commonly used representations such as graphic simulations and cladograms, while depicting change over time, fail to provide insight into its underlying mechanisms. We have been working on developing a restructuration for evolution in the context of DeltaTick, a block-based programming interface in NetLogo. Our goal is for students to build, debug and refine models of evolutionary processes using block-based primitives in DeltaTick. We first describe the underlying motivation, and then describe the design work we have done so far. We conclude with a discussion of challenges and design tensions.

Keywords

Block-based programming, Restructuration, Modeling, Evolution

Introduction

Technology is rapidly transforming the representational basis of science education. Advances in new media technologies are making it possible for students to engage in science and mathematics with more ownership and enjoyment, and at younger ages than ever before. These advances can be leveraged to develop new representational forms or "restructurations" to encode disciplinary knowledge (Wilensky & Papert, 2006; 2010).

In this paper, we describe a restructuration for processes underlying micro- and macro-evolutionary change. This restructuration is being designed in the context of DeltaTick (Wilkerson-Jerde & Wilensky, 2010), a block-based programming interface in NetLogo (Wilensky, 1999). The motivation underlying the restructuration is twofold; one, the paucity of rich representational building environments for evolution; and two, to develop an environment in which students can engage their productive intuitive knowledge about evolution to make sense of it.

Building Models of Evolutionary Change

Evolution undergirds the ever-growing domain of the biological sciences (Gould, 2002; Kitchener, 2007). Dobzhansky's famous and often-quoted remark, "Nothing in biology makes sense except in the light of evolution" neatly captures the centrality of evolution to the biological sciences (Dobzhansky, 1973).

Popular representations of evolutionary change such as cladograms and graphic simulations have been widely studied for their impact on student learning (Ainsworth, 2009; Evans et al, 2010; Matuk & Uttal, 2009; Soderberg & Price, 2003). While these representations depict change over time, they fail to provide insight into the mechanistic underpinnings of evolutionary change. They do not represent *how* populations change over time. However, in order for children to develop a meaningful understanding of evolution, we think it is essential they have access to the underlying mechanisms of evolutionary change to be able to make sense of this long-term phenomenon.

Agent-based models have shown great potential in helping students learn about mechanisms underlying systems by restructurating scientific disciplines such as physics (Sengupta & Wilensky, 2009), chemistry (Levy & Wilensky, 2009), material sciences (Blikstein & Wilensky, 2009) and calculus (Wilkerson-Jerde & Wilensky, in review), to make complex and inaccessible scientific content engaging, easier to visualize and learn.

Some prior work has addressed using agent-based representations to teach evolution (Centola, McKenzie & Wilensky, 2000; Wilensky & Centola, 2007). An agent-based modeling curriculum, BEAGLE (Biological Experiments in Adaptation, Genetics, Learning & Evolution), which primarily focuses on guided exploration of models, has been found to facilitate learning in eighth grade science classes (Wilensky & Novak, 2010, Wagh & Wilensky, 2012). Work done on building models of evolution has also found that it fosters deep learning (Wilensky & Centola, 2007; Xiang & Passmore, 2010).

We were interested in developing a domain-specific programming environment in which kids could quickly build models of evolution without having to do extensive programming, for several reasons. First, building fosters deep and meaningful learning (eg. Bamberger, 2001; diSessa et al, 1991; Nemirovsky & Tierney, 2001; Papert, 1980). Moreover, building models enables learners to think about the mechanisms underlying a system (Wilensky, 2003; Wilensky & Reisman, 2006). Secondly, through interviews with middle school children, we have found that children have a rich repertoire of knowledge about affordances and constraints of variations in populations that influence changes in an ecosystem (Wagh & Wilensky, 2011). Building serves as a medium for students to make their thinking visible by externalizing their mental representations (Papert, 1980; Lehrer & Schauble, 2000). The activity of building, debugging and revising models will enable learners to engage, refine and revalidate this repertoire of knowledge.

In this paper, we discuss the design of a model-building unit in evolution in DeltaTick (Wilkerson-Jerde & Wilensky, 2010), a block-based programming interface in NetLogo (Wilensky, 1999). The graphical interface of DeltaTick allows for quick constructions of models with semantic meaningfulness at the domain level. These constructions are made using domain-specific block-based primitives/procedures. Each block represents self-contained and autonomous fragments of code or procedures that function as rules of behavior for agents in the system (Kahn, 2007).

In what follows, we describe our ongoing design work. Specifically, we describe some of the new features of DeltaTick and then discuss some of the design challenges.

DeltaTick: The Design

DeltaTick was originally designed and built by Wilkerson-Jerde & Wilensky (2010). In this design project, we are doing further design work in DeltaTick to make it a felicitous environment to model evolutionary processes. The overarching goal of this project is to restructurate micro and macro evolutionary mechanisms into blocks that serve as primitives for model-building. These block-based primitives represent agent-level interactions that underlie evolutionary change.

When interacting with DeltaTick, learners can build models of ecological systems by defining one or more species and/or an environment for the species. They can then assign blocks or behaviors to the species to model different kinds of agent-level interactions, run the model, and then debug or revise it. The goal is for learners to engage in model-building to fluidly navigate between aggregate-level evolutionary change and agent-level interactions that results in that change.

***Trait Blocks*: Define traits & variations for a species**

Species (breeds, in NetLogo parlance) created in DeltaTick can be assigned variables to model variation in a population. A variable is presented as a *Trait* and values corresponding to a variable are called *Variations*. Learners can assign *Traits* to *Species*, and define *Variations* for a *Trait*. For example, a learner can create a species, "frogs" and then define a trait such as "color of skin" and "red" and "green" as corresponding variations for the trait.

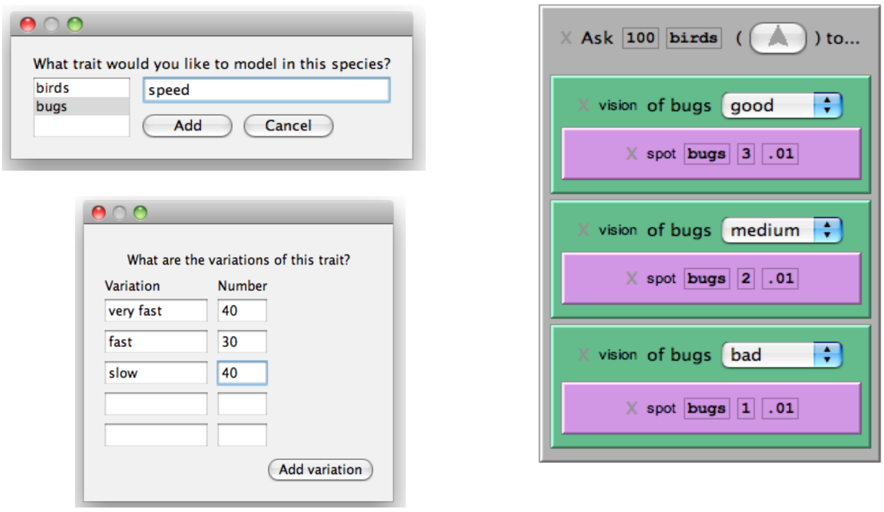

Fig 1: LEFT: Selecting a trait & variations; RIGHT: Assigning behaviors in TRAITBLOCKS

Once a trait is defined, it is represented as a TRAIT BLOCK in the environment. Each TRAIT BLOCK has a drop-down list of *Variations* defined for that *Trait*. Learners can use a TRAIT BLOCK in their model to assign behaviors with different probabilities to individuals with different variations. For instance, in the case of frogs, a learner could build a model in which Red-Frogs are eaten with a probability of .4 while Green-Frogs are eaten with a probability of .1 when the frogs live in a pond with green weed.

The goal is to enable learners to assign behaviors with different settings for individuals with different variations.

***Behaviors blocks*: Blocks as primitives. Blocks as procedures**.

In DeltaTick, a behavior block represents a fragment of code that encapsulates a procedure. These blocks represent rules for the individuals in the world to follow. We have developed a library of blocks that, we believe, are moderately generic in their ability to capture a variety of scenarios of natural selection.

Each behavior block comes with input boxes that allow learners to specify certain values for a particular behavior. For instance, one of the blocks in the library is called CHASE. The CHASE block comes with four input options; who?, at-what-speed?, notice-within-what-distance?, and probability-of-chasing?. Similarly, SPOT is a block that is accompanied by three inputs; who?, within-what-distance?, and with-what-probability?. These input boxes enable learners to specify, at a finer-grained level, the nature of individual-level interactions. For instance, by varying the input in "within-what-distance?" of the SPOT block, learners can model variation in the ability to sense (see, hear, smell or touch) other individuals in the environment. (see Figure 1)

We're currently working on developing libraries for other evolutionary processes such as genetic drift and speciation.

Environment Blocks

Learners can also select an environment for the species they have created from a list of pre-defined *Environments* in DeltaTick. In its current version, an *Environment* is conceptualized as a resource that provides food for the *Species* (eg. Grass). The *Environment* is represented in the form of patches in the NetLogo model. When food (grass) at any patch is consumed, the model waits for a pre-defined period of time before growing grass. *Species* and *Environments* can interact with each other. Each *Environment* comes with a library of block-based primitives specific to it (eg. Grow-grass).

Operator Blocks

When building models within DeltaTick, learners can also build an OPERATOR BLOCK. These blocks allow learners to assign behaviors to more than one group of individuals at one time. For instance, imagine a model of a fictional species, Bogsters that vary with respect to their color and strength-of-legs. A learner can define an OPERATOR BLOCK to assign behaviors to individuals who are red and short-legged. These blocks can be defined using the "and", "or" or "neither" operator.

Challenges & Design tensions

As we continue working on the design of this environment, we find ourselves grappling with two design tensions. The first one involves designing primitives of the right size that are generative enough in their ability to build different kinds of models, and yet are meaningful to middle school children. It is very important to us that learners feel that their intuitive knowledge is relevant, and more importantly, legitimate, when building models. In alignment with this priority, our focus has been to parse mechanisms of evolutionary change into block-based primitives that will make sense to middle school children. This focus has proved to be a challenge especially in designing a library for macroevolution.

A related design tension lies in seeking a balance between making the environment open-ended so learners can build personally meaningful models, and pre-designing a library of blocks that are adequate and meaningful in the context of undetermined species and traits. These tensions continue to influence and inform our design decisions as we further develop this environment.

Acknowledgements

A majority of this work has been done in the context of learners exploring models of evolutionary change. Exploration involves running experiments with pre-built models in which the agent-level mechanisms had already been coded for the students.

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RoboBuilder: A Program-to-Play Constructionist Video Game

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Abstract

As the popularity of video games continues to grow, we see the medium as an increasingly important venue for giving young learners an opportunity to engage in constructionist learning. This paper introduces RoboBuilder, a blocks-based programming game that draws on constructionist design principles as well as video game norms to create a fun, challenging computational learning environment. After describing the game and discussing previous work that informed its design, we introduce two innovative features of RoboBuilder.

Keywords

Video games, Low-threshold Programming Environments, Visual Programming, Design

Introduction

The constructionist community has a rich history of creating innovative computer-based learning environments. These environments range from exploratory microworlds to story and game authoring environments to scientific modelling tools. In this paper we introduce RoboBuilder, a constructionist video game, and discuss some of the interesting features that arise when bringing constructionist design principles to the video game medium. RoboBuilder is a blocks-based programming game that seeks to introduce players to fundamental programming concepts through challenging and fun gameplay. This paper proceeds with a description of RoboBuilder and a review of prior work that inspired RoboBuilder's design. We then present two innovative aspects of the environment before discussing the next steps in our research agenda.

Meet RoboBuilder

RoboBuilder (figure 1) is a blocks-based programming game that challenges players to design and implement strategies to make their on-screen robot defeat a series of progressively more challenging opponents. The players' on-screen robot takes the form of a small tank, which competes in one-on-one battles against opponent robots. The objective of the game is to defeat your opponent by locating and firing at it while avoiding incoming fire from your adversary. Unlike a conventional video game where players control their avatars live during battle, in RoboBuilder, players must program their robot before the battle begins. To facilitate this interaction, RoboBuilder has two distinct components: a programming environment where players define their robot's strategy, and an animated robot battleground where their robot battles. Players first use the programming interface to implement their robot's behaviours before hitting the 'Go' button, which launches the battleground screen where the programmed strategies are enacted by their robot as it competes. To implement their strategy, players are provided with a set of language primitives to program their robot; the language includes movement blocks (ex: *forward*, *turn left*, *turn gun right*, *fire*) to control their robot's motion, event blocks (ex: *When I See a Robot*, *When I Get Hit*) to control when instructions will execute, and control blocks (ex: *Repeat*, *If/Then*) that can be used to introduce logic into their robot's strategy. The battleground interface is read-only; once the battle starts, players cannot interact with or alter their robots.

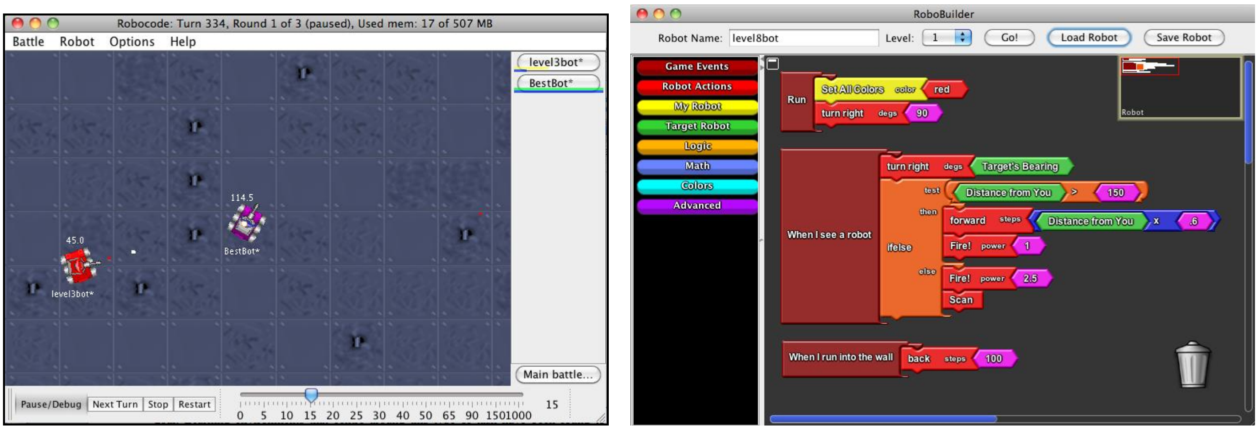

Figure 1. RoboBuilder's two screens. The battle screen, on the left, is where players watch their robot compete; the construction space, on the right, is where players implement their strategies.

The overarching learning goal of RoboBuilder is to give players the experience of developing and expressing ideas in a computational medium. The design of the game is also intended to enable learners to become comfortable using general programming strategies such as incremental development, breaking larger goals down into subtasks, and using feedback from prior runs of a program to inform revisions. Over the course of game play, we aim to give players a new understanding of what it means to program while fostering general-purpose programming skills that have broad application beyond our game.

There are three main reasons we decided to make a robot-battling task the objective of our game. First, programming robots to accomplish specific tasks has been found to be fun and motivating in both a video game context as well as in learning contexts (Berland & Wilensky, 2004; Hancock, 2001; Martin et al, 2000). Second, the body syntonic nature of controlling the robot and the direct mapping of programming blocks onto in-game behaviours makes gameplay accessible to players with no prior programming experience. Finally, as educational researchers conducting design research (Edelson, 2002), rapid prototyping and iterative development is important to our research agenda. Thus, we built our game on top of Robocode (Nelson, 2001), a problem-based learning environment. This allowed us to have a working prototype early in the research process.

Previous Work

Low-Threshold Programming Environments

A great deal of work has been done on the design and implementation of programming languages and environments for beginners (for a review see: Guzdial, 2004 or Kelleher & Pausch, 2005). One design strategy for novice languages that has gained popularity is a visual programming approach that presents language primitives as on-screen objects to be assembled using a drag-and-drop interface. These blocks-based environments have also been called "component-oriented microworlds", where components are autonomous, reusable computational objects of varying technical and behavioural complexity (Kynigos et al., 1997). In these environments, programming takes the form of combining components, or groups of components, to create complex, composite structures that carry computational meaning.

RoboBuilder's programming interface is a modified version of the OpenBlocks framework (Roque, 2007), which is an open source Java library used to create blocks-based programming environments. This library allows the language designer to define the set of primitives as well as the shape of each block, which in turn dictates how and where the pieces can be used. Blocks-based programming languages, like LogoBlocks (Begel, 1996) with its snap-to-compile feature, and environments, like Scratch (Resnick et al., 2009) with its stage where programs are visually run, have influenced RoboBuilder's language and the design of its interactive construction space.

Video games as learning environments

Video games are becoming increasingly pervasive in youth culture. The potential of video games as learning environments was recognized by Papert who wrote that they empower children to "test out ideas about working within prefixed rules and structures in a way few other toys are capable of doing" (Papert, 1993, p. 4). A growing body of work has argued that video games are an effective medium for teaching and learning (Prensky, 2001). Gee (2003) argued that video games are the source of a powerful new literacy with benefits ranging from identity formation to reasoning skills. The benefits of video games extend beyond in-game learning, as social aspects of video games are similar to effective non-virtual learning environments (Stevens et al., 2007).

Making Game Play a Constructionist Activity

Marrying constructionism and video games is not new. A number of constructionist learning programs have made video games a central part of their learning agenda (Goldstein et al., 2001; Harel & Papert, 1990; Kahn, 1999). For example, Caperton, in her work with Globaloria, has been very successful appealing to kids by having video games be the output of constructionist learning environments (Caperton, 2010). RoboBuilder seeks to leverage video games to serve a similar motivational purpose, but does so in a very different way; instead of constructing games, in RoboBuilder the player-created constructions are actually used to play the game. This approach is not without its challenges. By making the learner-constructed artefact the mechanism for playing the game, we are faced with what Noss and Hoyles call the "play paradox" (1996). On the one hand, RoboBuilder offers an engaging exploratory environment that supports many ways of solving the proposed problem; on the other hand, there are specific learning objectives we have for RoboBuilder. How can we be sure that the players are learning what we have designed the environment to teach? One solution is to design the environment such that "the system carries with it elements of what is to be appreciated" (Noss & Hoyles, 1996, p. 132). This idea fits very naturally into a video game context. A central goal of RoboBuilder is to give players the experience of developing ideas with and expressing ideas in a computational medium. Because RoboBuilder has a clear goal (defeating your opponent) and easily identifiable notion of success (winning the match), the game rewards players who successfully encode their strategies with the provided computational form. In this way the player's goals (to win the match) are aligned with our learning goal (players learning to encode ideas in a computational medium).

Video Games for Situating Programming Abstractions

By framing RoboBuilder as a video game and making programming the central activity of gameplay, we seek to put the player in a problem-solving context that challenges them to computationally implement potential solutions to the in-game objective. Thus, we use the game as a way to situate the programmatic abstractions the player must use to participate. The language primitives develop meaning for the player through the iterative, construction process central to gameplay. “These meanings become reshaped as learners exploit the available tools to move the focus of their attention onto new objects and relationships” (Noss & Hoyles, 1996, p. 122). In this way, players are “abstracting *within*, not *away from*, the situation” (Noss, Healy, & Hoyles, 1997, p. 228, emphasis in origial). By having players express their ideas in the computational medium and then witness their expressed ideas enacted, the video game provides an opportunity for the learner to interact with the representational system and form rich connections with the language elements and the computational behavior they embody. These once abstract language primitives undergo a process of “concretion” (Wilensky, 1991) for the learner, whereby they develop meaning in the context of the game.

RoboBuilder’s language primitives and interface were designed to facilitate this concretion process. When developing such environments, it is essential that the designed representational system “provide ‘natural’ expressive power - the right things to talk about, and ways to talk about them” (Hoyles, Noss, & Kent, 2004, p. 320). We achieve this “natural expressive power” by providing a language that blends blocks with clear in-game meaning (like: *Turn Right* and *My Energy*) with conventional programming blocks (*Repeat*, *While,* and *If/Then*) that could be used to bring the player’s envisioned strategies to life. In this way, RoboBuilder is an example of a component-oriented microworld that gives the player the ability to “build and think in terms of objects that are close to their domain of interest” (Kynigos et al., 1997, p. 231). We use the video game context, and the dynamic interactive challenge that comes with it, to situate programming abstractions and motivate players to computationally reify their imagined strategies with a programming language designed to fit with the challenge at hand.

Where video games excel as contexts for situating programmatic abstractions is their ability to encourage and foster constructions of increasing complexity and size. Video games can reward small and simple programs, but also include incremental challenges that require the learner to create more advanced, complex programs. Thus, a video game can not only be a low-threshold, high-ceiling programming environment, it can also include a built in mechanism to encourage learners to progress from basic programs to more advanced, sophisticated constructions.

Conclusion and Next Steps

This paper introduces RoboBuilder, a program-to-play constructionist video game designed to give younger learners a chance to develop and apply programming skills in a fun and motivating context. We are currently conducting a pilot study where we record and clinically interview participants as they play the game. These preliminary sessions have shown RoboBuilder to be an engaging and motivating environment and we have observed some of the desired learning goals enacted by participants during gameplay. As for our larger research agenda, we see RoboBuilder as the first in a series of similar constructionist video game we will design. We recognize that the task of controlling a tank-like robot and shooting at enemies may only appeal to only a subset of learners; particularly boys, a population already over-represented in the field of computer science (Margolis & Fisher, 2003). Based on our findings from RoboBuilder, we hope to create more such environments that use the same program-to-play approach but have different in-game goals, use different language primitives and appeal to different (and hopefully even wider) audiences.

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Logo-based activities for learning counting for children with Down syndrome

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Abstract

In this paper we present four Logo-based activities that were designed as part of a study to help children with Down syndrome (DS) learn counting and the concept of quantity, through the construction of figures and paths. The activities were piloted with a couple of normal 6 year-old primary school children and then tried out with three children with DS of 12-13 years of age. Some of the activities were easier and more enjoyable than others. In regards to how the activities helped these children in the learning of counting, the study was inconclusive, though the children with DS did show much more engagement with the computer-based activities than they had done with other concrete materials and did show progressive improvement over the sessions that may indicate they derived some benefit from engaging in these activities.

Keywords

Down syndrome; children; counting; Logo; constructions

Introduction

We present here a research project that intended to help children with Down syndrome (DS) develop their abilities in counting and the concept of quantity through their engagement of some Logo-based activities that involved constructing figures and paths. We begin by discussing some of the challenges that persons with DS face; then present the activities and finish with some results from their implementation with three 12-13 year-old children with DS.

Some of the challenges for people with Down syndrome

Persons with Down syndrome (DS), besides having some physical afflictions, also have some intellectual and cognitive handicaps. They tend to be slow to process and codify information, and have difficulties in interpreting it. They also have difficulties in dealing with several variables at once. Additionally, their spatial and temporal orientation is not as well developed; they also have problems with arithmetic computations, particularly mental ones. In terms of memory, though they can have some difficulties in retaining information, they have well-developed procedural and operational memory, so they are capable of carrying out sequences of tasks with precision. On the other hand, they have difficulty following a sequence of more than three instructions. Their visual retention capacity is higher than their auditory one (Flores & Ruiz, 2004). One of the areas of biggest handicap, is the area of language. Persons with DS tend to have a late emergence of language and language skills, although this is highly variable amongst individuals (Miller, 2001, in Flores & Ruiz, 2004).

From an educational perspective, the above issues have some implications which need to be taken into account. First, the attention-deficit problems that persons with DS tend to have, imply that instructions need to be given more gradually in a detailed and precise way. Since visual processing is easier than the auditory one, the visual channel should be emphasized, particularly for giving information. In general, teaching needs to be gradual and individualized since different children require a different number of repetitions and also have different response-times (Ruiz 2006).

Taking the above into consideration, and inspired by the work carried out by Weir (1987), we believe that computer-based activities can be helpful in the teaching mathematical content to children with DS (as has been shown by researchers such as Ortega-Tudela, 2008): for example, by helping in the information perception and processing. Also, computer activities can be more adaptable to the individual needs that persons with DS require.

On counting

Counting requires putting into correspondence objects in a set, with the conventional set of natural numbers. The first methods of quantification are *subitizing*, which refers to the process by which small sets are immediately quantified without the need to count all of its elements; and *estimation*, used for larger sets to guess its number of elements without really counting the elements. In more advanced stages of counting, it involves one-to-one correspondences; stable order; cardinality; abstraction; and irrelevant order (Gelman & Gallistel, 1978).

Baroody (1988) showed that children with slight mental retardation (not specifically with DS) were capable of counting. However, other researchers have found that mentally retarded children exhibit learning by repetition rather than understanding the basic principles of counting (Brown & Deloache, 1978; Cornwell, 1974); this implies a restriction in the flexibility towards counting: thus, when children with DS learn to count by ordering objects, they later have many difficulties in changing those structures.

Logo-based activities for promoting the learning of counting

Figura 1. Interactive button area for the first activity (left) and second (right) activities

In order to try to help students with DS learn counting and the concept of quantity, we designed some activities for them, using MSWLogo. As will be further described below, these activities involved constructions by the children of figures made out of squares blocks, or of paths; in order to successfully carry out the activities, children had to count, though they also learned through trial and error. Because of their limitations in using language, we created buttons for them to move around and add or remove objects such as squares (see Figure 1). The commands were very basic (up, down, left, and right) and placed in a manner similar to the movement arrows on the computer; as well as other simple commands, such as for adding (*Pon*) or removing (*Quita*) the square blocks with which they would draw (see activities below); we also included a New (*Nuevo*) button to clear the screen to begin a new drawing. Also, although we included some text in the activities, this was read and explained to the students.

The Drawing with Squares activity

The first activity (Figure 2) came about due to the interest that the children had in using a computer program to draw. With this activity, children could draw figures by adding squares or blocks (one at a time). We wanted to use it to see if the children realized that when the complexity of the drawing increased, it was because they were using a bigger number of squares.

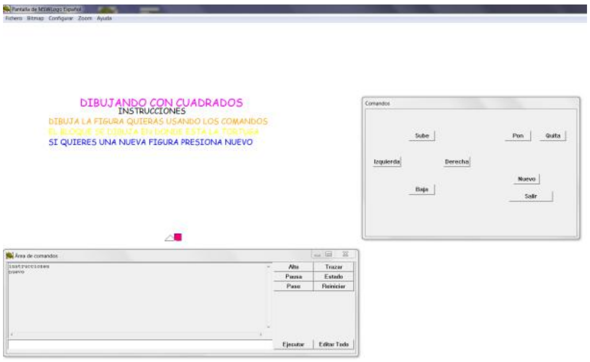

Figure 2. Initial screen of the Drawing with Square Blocks activity

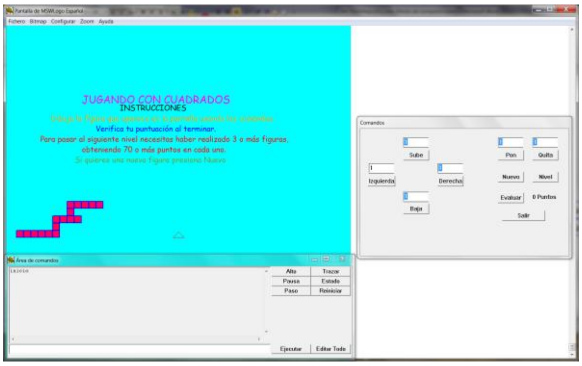

Figure 3. Initial screen of the Playing with Blocks activity

The Playing with Blocks activity

In the second activity (Figure 3), a figure is given and students have to reproduce it. The activity is presented as a game that gives points for achieving correct enough figures. Students have to build at least three figures of a minimum of points if they want to be able to go on to a next level.

In this activity we added the possibility to add (or remove) or move by more than 1 square block, to see if students would count the blocks in parts of the given figure and add the corresponding amount in their own drawings.

The Labyrinths activity

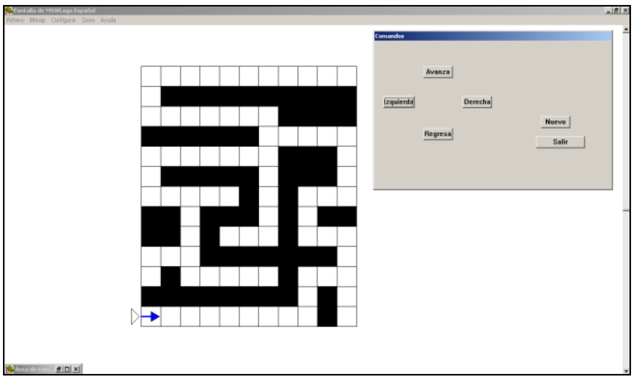

Figure 4. Initial screen of the Labyrinths activity

In the third activity (Figure 4), we not only wanted for the children to work with counting but also with laterality. An important difference of going through the labyrinths on the computer vs.

doing it with pencil and paper, is that the children are forced to specify how many steps (in this case squares) the Logo turtle has to walk and in which direction. We designed a set of 10 different labyrinths with different levels of complexity through which children can progress as part of the "game".

The Following Paths activity

The fourth and last activity, was the most complex one. Here, children could construct one of three paths to reach the goal. We included a number line and an operation line to record the steps taken in terms of what had been added and subtracted along the path, so that children could see these numbers and operations with the aim of helping them develop number and operation sense.

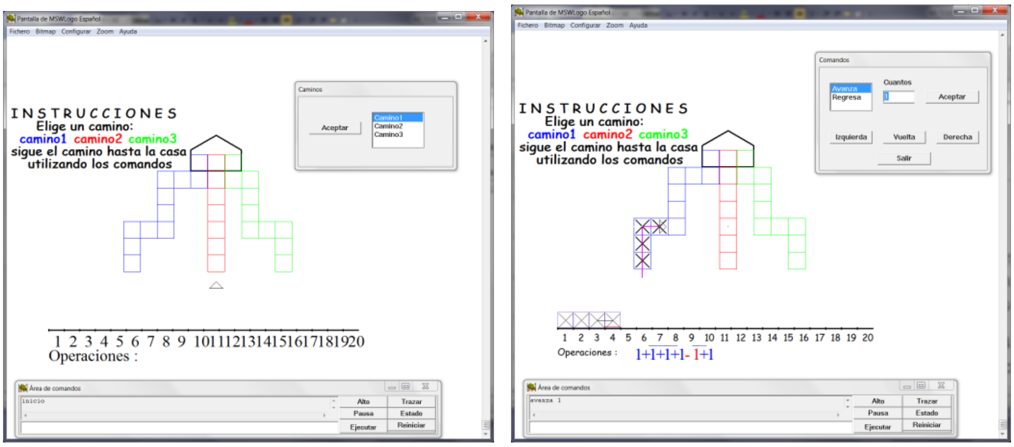

Figure 5. Initial screen (left); and screen half-way through the Following Paths activity (right) where the operations showing the steps added (or subtracted) are shown below.

Some results

The activities were piloted with two normal 6 year-old children in primary school and then were carried out with three children (two girls and a boy) with DS, of 12-13 years of age, that studied in a public school for children with special needs (called Center for Multiple Attention) in Tlaxcala, Mexico. The normal children very successfully carried out the activities, engaging in them, enjoying them very much (particularly the game in activity 2), and also displaying much creativity. The DS children initially needed a period to learn to play and move, understanding what each button did, as this was not straightforward for them. In a second session, children enjoyed randomly creating some drawings. One of the girls, whom we call here Monica, did not like pressing the buttons herself with the mouse or keyboard, so she would point at the screen at what she wanted and the teacher would press them for her.

The boy, whom we call here Israel, spent the second session filling out the screen with random paths. On the third day, he began wanting to draw closed figures (although he had some trouble distinguishing between left and right). On the fourth day, he enjoyed drawing "paths" as he called them, and also began wanting to construct a square, but had some difficulties. The next day he finally achieved drawing a quadrilateral on his own (Figure 6) and with no help from the teachers. But he remained obsessed with drawing closed figures: even when he wanted to draw a staircase, he had to draw a staircase as a closed figure (Figure 7). Monica also achieved constructing a square, also on her own (though by directing the actions to the teacher); she liked to "direct" drawings but did not show much interest in the other activities.

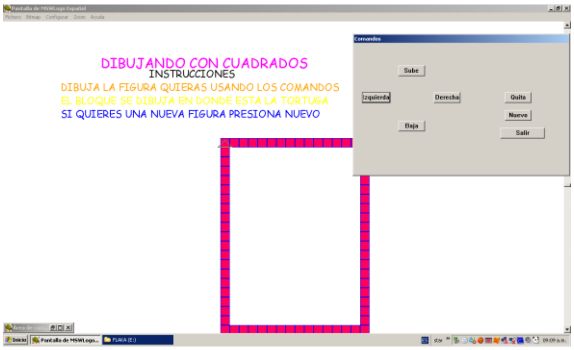

Figure 6. Israel's first quadrilateral.

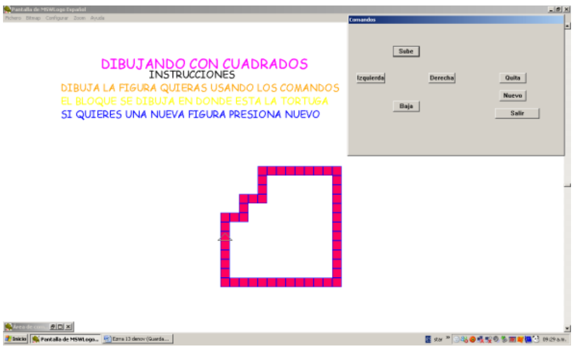

Figure 7. Israel's staircase.

We started the third activity (the Labyrinths activity) about a month after the children had first started with the computer activities, but we always had to combine this activity with the drawing one, since it was the one children enjoyed the most (possibly because it was the most constructionist one of them all). Through trial and error (i.e. correcting their wrong turns) children were able to solve the labyrinths: Israel realized after a couple of sessions that if he made a wrong turn, he could correct it by turning more times in the same direction.

The fourth activity turned out to be too complex for these children, and they kept asking to go to the drawing activity, so we couldn't work on this one much.

In regards to how the activities helped these children in the learning of counting, the study was inconclusive (we used pre- and post- assessments to measure their counting abilities: only a mild improvement was detected), though there was some indication that with more time working with them, we may have achieved better results. Israel did learn to name numbers, though. More significantly, the children showed much more engagement with the computer-based activities than they had done with other concrete materials and did show progressive improvement over the sessions: their drawings became more complex and they were able to construct them on their own, which is indicative that they benefited from engaging in these activities.

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Construction and Design Activities through Logo based 3D Microworld

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Abstract

Physical construction kits equipping motor or motion sensor and connecting Logo programming with traditional LEGO bricks have been actively introduced in recent years. Activities that utilize such physical construction kits may provide students with learning experience which engages them with creative thinking and problem solving. However there are some practical and physical limitations when using such kits in education due to their expense, weight and volume. This research would introduce constructionism based activities that utilize LOGO based 3D representation system (Cho et al., 2010) to construct mathematical creative artefact by expressing construction kits like LEGO bricks and Soma cubes with semi-formal symbolic expressions. We conducted a creativity contest utilizing semiotic symbols based on turtle metaphor and Web 2.0 educational platform, and we would report its educational implications.

Keywords

Mathematical activities, 3D representations, creative artefact, semiotic symbols, turtle metaphor

Introduction

Spatial ability, as one of the important factors of human intelligence, is a cognitive function that is often used in various academic areas like mathematics, architecture and medical science as well as in our daily life activities like driving and swimming. Developing spatial ability is one of the major objectives in math education; therefore elementary school's math curriculum in Korea includes 'building block' which deals with 3D objects, and building blocks and soma cubes are often used as construction kits. However, it is still challenging to visualize 3D objects on a 2D paper and also physical limitations in using such kits are followed. Thus, a technology environment where students can construct and visualize objects is required in order for them to explore 3D objects.

Logo constructs geometrical objects with 'forward' and 'rotate' commands and this shares a fundamental philosophy with LEGO bricks which build a variety of 3D objects with basic blocks. Based on the basic ideas of LEGO, Cho et al. (2010) designed a representation system in a virtual microworld[1], which constructs 3D building blocks as LEGO bricks do. This is composed of

[1] Cho et al.'s 3D representation system (2010) is implemented in JavaMAL Microworld and the website address is as follows: http://www.javamath.com

simple symbols which elementary school students can learn easily by overcoming the problems occurred in the existing 3D Logo and minimizing the difficulty of program languages. That is, turtle symbols that construct 3D blocks consist of s (moving forward), L/R (turn left/right) and u/d (moving upward/downward) by using turtle metaphor. An example of constructing 3D objects with these turtle symbols is shown in Figure1.

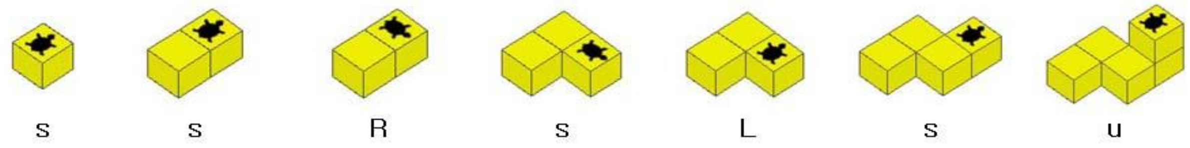

Figure 1. Logo-based 3D Representation System

Coming back to LEGO again, more advanced products including LEGO/Logo, programmable bricks and LEGO's WeDo have been recently developed by connecting Logo programming with traditional LEGO bricks (Resnick et al., 1996). This is to enable students to go through hands-on learning experience that actively engages them with creative thinking, team work and problem-solving skills by merging computer programs with traditional static LEGO bricks or equipping dynamic motor or motion sensor.

Based on Cho et al. (2010)'s 3D representation system, we will introduce activities that can be learned through design as constructing construction kits like building blocks, soma cubes and LEGO bricks dynamically and expressing them with semi-formal symbols in a virtual environment, and will study educational implications that can be found in such activities.

Figure 2. LEGO's WeDo

Activities Engaging Mental Construction thru Physical Construction

We conducted a creativity contest where students build virtual LEGO bricks in a virtual environment using 3D representation system developed by Cho et al. (2010).[2] This contest was based on the constructionism - knowledge is constructed in the context of building personally meaningful artefacts in a media environment (Kafai & Resnick, 1996). The contest lasted for one month including 3-week preparation and 82 students ages 12 to 13 participated. During the 3 week contest preparation period, students learned turtle symbols that construct basic blocks, angle adjustment commands (ddv, rrv), spring command (e) that orders a straight-line motion and engine command (E) that orders a rotary motion through online video lectures, texts and JavaMAL Microworld screens. Then, they were required to submit a given task every week by using symbols and commands learned. During the last one week after the preparation period was over, students submitted their own creative artefacts by applying all commands learned and all tasks previously submitted. In all tasks and the final artefacts, all commands used and explanations were required to be included. We also encouraged communication among students by posting all tasks in the internet. With a theoretical background, we would study educational implications shown in the contest activity by looking at artefacts students submitted.

[2] The creativity contest was conducted in the website below where JavaMAL Microworld is in. http://mentoring.snu.ac.kr/siheung

1. Creative Thinking through Design

Activities that make a certain object as instructed in the manual in physical construction like LEGO can be 'hands-on leaning' or 'leaning-by-doing', but they cannot be learning-through-designing (Resnick & Silverman, 2005). Design tools should enable people to design, create and invent things (Papert, 1980). While preparing the contest, it was observed that students as 'designers' gradually developed their own artefacts in a creative way as they designed and created their objects. For example, the second task was to make artefacts by using engine command (E), which orders rotating. Figure 3 shows one student's outcome after he learned basic commands of building blocks and engine command (E). This student made a 'wind generator' in ① by applying a pinwheel which was a initial task and evolved it to an 'advanced wind generator' in ②. ③ are symbols that construct ①, and ④ and ⑤ are student's explanation on his artefact ① and ② respectively.

④: It's a wind generator applied from a pinwheel, the initial task. It's simple and easy, isn't it?
⑤: This is an advanced wind generator. Doesn't it look a bit complicated? It is amazing I could make it that complicated even if it was my first try.

While ① is a simple wind generator which use four engines only, ② is evolved from ① and turns out to be an 'advanced wind generator' in which thirty engines run complexly. Observing changes of the artefact from ① to ②, we suppose engine command (E) that orders dynamic action motivated and stimulated him to think creatively. As the student performed tasks in different stages, he was able to complete a more creative and well-made artefact and admired his own work. This learning environment not only engages learners in composing artefacts, but also encourages them to explore the ideas underlying their constructions.

2. Problem Posing and Problem Solving through Interaction

Hoppe at al.(2005) mentioned workspaces which can share visual objects provide a new channel on interaction by encouraging communication among people. The environment where the creativity contest held is a semiotic microworld (Cho et al., 2011) expressed in both 'visual object' and 'semiotic symbols' and this helps us understand learners' thought process of how visual objects are constructed through the symbol structure. In addition, learners can reflect on their thought by observing the visual object outcome resulted from the symbols that they enter and also can correct their errors by manipulating symbols. The following case shows the process how one student who made a globe solved the problem posed by her mentor and peers – Earth's axis is tilted 23.5 degrees.

Ahn(peer): The earth's axis is tilted 23.5 degrees.

Lim(learner): Sorry, but I'm still having a trouble with angles. If I put ddv=23.5 as a command, then I cannot make a globe. Help me…

......

Yang(mentor): Please check the hint given on the bulletin board.

Lim(learner): Wow, great. Thank you

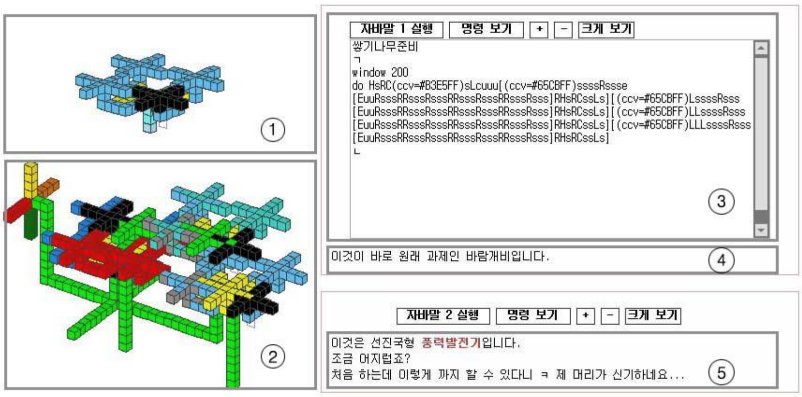

Figure 3. Learning through design

. …..

Wan(peer): Now, the globe rotates perfectly.

Duck(peer): Could we see the angle of 23.5 degrees?

Spongesong(peer): It's just like a real globe.

Yang(mentor): You couldn't make a perfect globe because you used m and o as commands. Actually, the commands you used were overused and this caused some facets to be overlapped. Only 36 times is enough to make a perfect globe. Do you know why? I'll leave this question as your homework. I also see you used the command - do (ccv=#DCDCDC)RRs[>s>s>s>s>s>s>s >s>s>s>[dd]suu[s]uRRssssds]RRsss- to make this axis. What do you need to do to make this axis symmetric?

Lim(learner): Thanks. *^^*

Lim(learner): I've got the answer to the problem. It's because I set rrv as 5 degree, if I rotate it 36 times, it turns out to be 180 degrees and consequently I can make a circle.

In the case above, we were able to observe 'affective expressions' like "The globe rotates perfectly." and "It's just like a real globe" as well as 'cognitive consideration' on angles and number of commands to tilt Earth's axis occurred to the students. The virtual microworld here works as an educational platform where learners can create, share and correct their artefacts by feedback and we regard it as a learning environment where learners pose problems in the context of the artifacts that they created, and solve them cooperatively.

3. Cognitive Thinking through Semiotic Symbols

Shaffer & Clinton (2006) introduced the concept of 'toolforthoughts' for the close reciprocal relation between tools and thoughts. In this ontology, there are no tools without thinking, and there is no thinking without tools; thus there are only toolforthoughts, which represent the reciprocal relation between tools and thoughts that exists in both. That is, moving forward from continuous reciprocal relation between tools and thoughts, they removed the distinction between the two and considered human cognition as something that works together with 'toolforthoughts'. We were able to find some examples of 'toolforthoughts' - symbols that students learned for the contest actually worked as a cognitive thinking tool.

'[ ]', one of the commands that students learned, was created to get rid of the step for turtle to go and come back to a certain point like the repeat mark in music. Turtle remembers its position and direction in '[', takes actions according to the given commands between '[' and ']' and comes back to '[' when ']' is commanded. Figure 4 shows an example of student's artefact that used a '[ ]' command. The student made one car wheel that can be created with the same structure of symbols. Then he created a symmetric command language using direction change as in ① and made the command language short by using double '[ ]' in the command. This shows '[ ]' symbol became toolforthoughts as this student's cognitive thinking tool to simplify the command language.

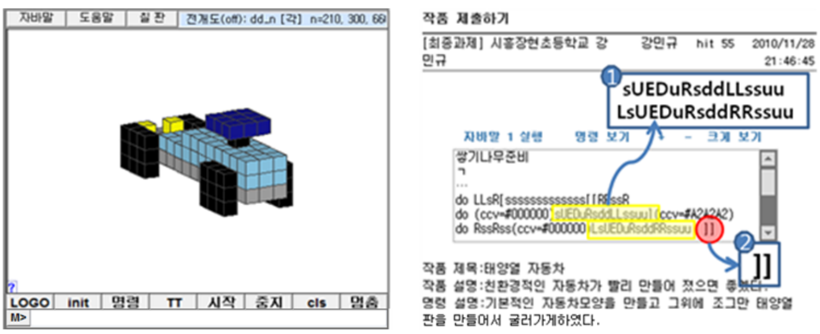

Figure 4. Usage of symbols as construction and thinking tools

Closing Remarks

We examined the activities to make 'dynamic LEGO bricks' through semi-formal symbolic expression based on turtle metaphor in a virtual microworld. In the activities, students were able to become designers who design and create their own objects by using basic blocks that construct 3D objects and symbols that enable the objects to make dynamic motions. In addition, the virtual environment worked as a Web 2.0 educational platform where learners could create and share their own artefacts and receive feedback on them. Learners in this environment also could pose any problems naturally and solve them in the context of artefacts created by them. Finally, as a cognitive thinking tool, semiotic symbols that construct an artefact became a 'toolforthoughts' through manipulation process.

As one who lives in France may pick up French naturally (Papert, 1980), the virtual microworld became a 'playground' which engages learners with creative thinking, problem posing, problem solving, and cognitive thinking. It can be further studied how concrete experience that constructs 3D objects with semiotics symbols affects educational situations like spatial ability or algebraic symbol introduction in an affective and cognitive way. Furthermore, rather than stopping this activity as a one-time event, it would need to be linked to advanced education that can 'learn' and 'inquire' and thus be resulted to an environment where we can practice 'Low Floor, High Ceiling and Wide Walls' (Resnick & Silverman, 2005).

Acknowledgements

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Dynamic tessellations in support of the inquiry-based learning of mathematics and arts

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Abstract

The paper presents an example of a didactic scenario illustrating the inquiry-based learning (IBL) as implemented in two educational projects 25 years apart. The message is that even when different computer environments are used (Logo and GeoGebra in this case) it is the constructionists' approach that is decisive for the learning outcomes.

Keywords

Tessellations, dynamic software, inquiry-based learning, mathematics congruencies, art

The inquiry-based learning – an aspect of the constructionism

The phrase *inquiry-based learning* is used to describe a process in which the students (usually under the guidance of a teacher) are"discovering" (possibly "creating") knowledge themselves by carrying out experiments, by formulating and investigating conjectures, by discussing and sharing with peers both ideas and products – the latter being an important component of the constructionism. Such an approach is relatively new in the context of the mathematics education and has been promoted in Bulgaria mainly since 1984 within the experimental schools of the Research Group on Education (RGE) (Sendova, 2011). The main principles behind the RGE educational philosophy were "learning by doing" and "integration of the school subjects" and they were extended beyond the RGE curriculum in the *Mathematics and Informatics* textbooks for the secondary schools (1988-1989) in Bulgaria (Sendova & Nikolov, 1989).

Problem solving scenarios in *Mathematics and Informatics* textbooks

The main questions addressed in these textbooks were: *how to feed curiosity, wonder and excitement in mathematics and informatics classes*; *what kind of projects and scenarios would keep up the students' attention for a longer period*; *how to provoke the exploration and discussions on the process of development*. Two ideas which turned out to be fruitful were:

- to include problem solving scenarios that could be developed both vertically (in grades) and horizontally (within the same grade)
- to apply the integral approach, i.e. to let the students see one and the same notion reflected in different contexts.

In one of the scenarios (appearing in the textbooks for 9th and 10th grade) the students acted as designers of wallpapers and tessellations by means of the Logo turtle geometry. The project started with design of motifs to be replicated in the nodes of a regular grid thus forming a wall-paper. When playing experimentally with different inputs of the wall-paper Logo procedure (corresponding to the type of the motif and to the distance between the gird nodes) the students could find out that the results were very sensitive even to small changes of the input values and that some new shapes might appear as a side effect. The *tessellations* – a special case of wall-papers in which the motifs interlock perfectly to fill the plane without gaps or overlapping, proved to be an object of exploration with a great appeal to the students. The tasks in the context of *tessellations* can be organised so that the students would have to combine mathematics and informatics skills of different level, e.g. to find all the regular polygons tessellating the plane, to generate the polygon-tiles simultaneously by means of multiple turtles (Blaho & Kalas, 1998), recursive procedures (Clayson, 1988), to modify the tessellating regular polygon by implementing geometric transformations such as *congruences* (translations, rotations, reflections and compositions of those) so as to obtain a tile with a new shape (Sendova & Grkovska, 2005; Chehlarova & Sendova, 2010). The latter idea can be easily implemented by means of dynamic software which we did in the frames of two European Projects dealing with the inquiry based learning (IBL) in science and mathematics.

Some recent developments of the IBL

The projects under discussion are *InnoMathEd* (Innovations in Mathematics Education on European Level) and *Fibonacci* (Disseminating inquiry-based science and mathematics education in Europe) (Kenderov, 2010; Chehlarova et. al., 2011). The Inquiry Based Mathematics Education (IBME) in the frames of these two projects has been promoted in Bulgaria at two levels – national, and local (in major regional centers) (Kenderov, Sendova, 2011).

The specifics of the teachers training courses was the variety of the audience. The school principals would often form groups of teachers from the primary and secondary school, teachers in mathematics, informatics, ICT, and sometimes even in science, arts, and history so as to gain a critical mass of teachers able to implement the IBL by means of dynamic computer environments. Thus the teacher educators had to introduce relatively new dynamic software (*GeoGebra*, *Geonext*, *Elica* applications for 3D explorations) for a couple of days in the context of didactic scenarios developed by the Bulgarian *Fibonacci* team in harmony with the curriculum (but not limited to it) and to demonstrate the inquiry-based teaching/learning process. The participating teachers experienced the potential of the learning environments specially designed (i) to support a joint work among teachers and students acting like a research team in which the teacher acts as a discovery-guide; (ii) to encourage students to find their own learning paths according to their interests and potential, and to build the knowledge in a cross-disciplinary context, especially integrating mathematics with IT, natural science and art (http://www.math.bas.bg/omi/Fibonacci/archive.htm).

What follows is an excerpt of a *Fibonacci* learning environment in the context of tessellations and its implementation in a class setting.

How to transform dynamically a square in a new tessellating tile

Let us illustrate the idea of dynamic tessellations by transforming a square tile in a tessellation tile of a new shape. We construct the square as a partial case of the *polygon* tool, select a point **E** on its side **AB** and a point **F** – on the segment **EB.** Then we construct an arbitrary point **M** and the images of **E, F** and **M** under translation by vector **AD.** Connecting the points as shown in the third picture of Figure 1 we get a newly shaped tessellation tile.

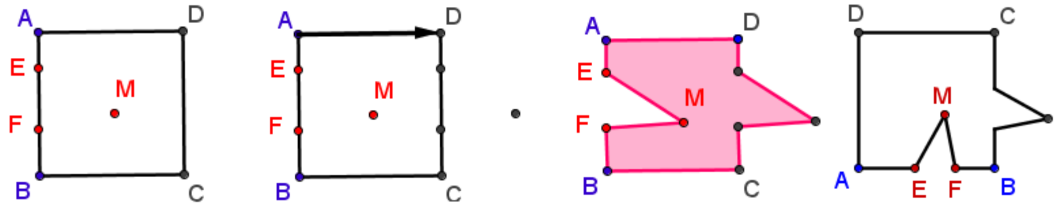

Figure 1. Transforming a square into newly shaped tiles

It is possible to transform the square in another way ─ let us construct now the images of **E**, **F** and **M** under rotation with center **B** and angle $-90°$. Connecting the points as shown in the fourth picture of Figure 1 we get another tessellating tile. Next we can get a module of four tiles by means of translation (Figure 2 upper left) or rotation (Figure 2 bottom left).

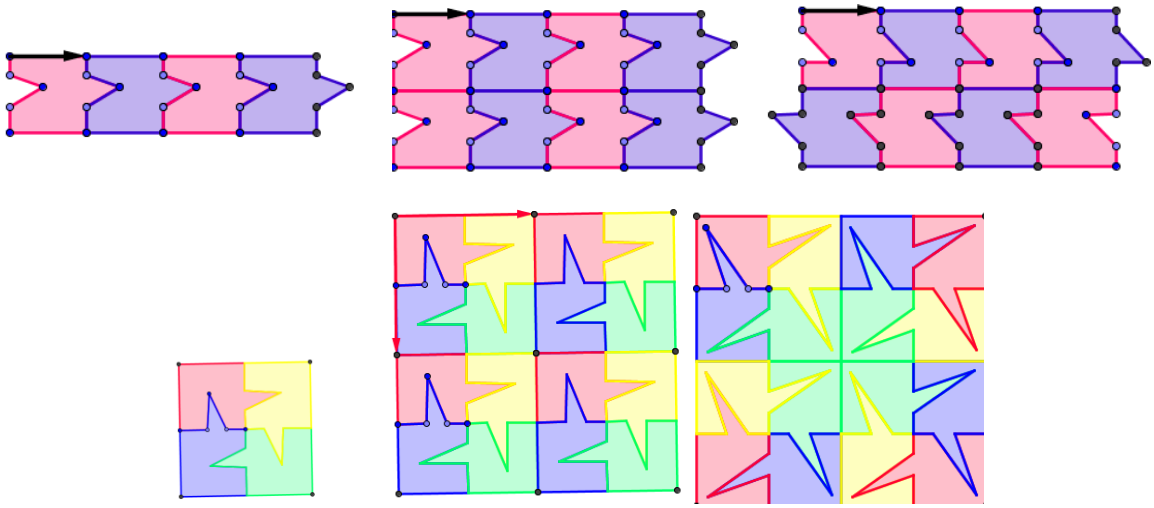

Figure 2. Constructing a module of tiles by translation and spreading it in various ways

The next steps could be carried out in various modes (by applying a translation, a central symmetry or reflection) which assures a great variety even with such a simple starting shape. Furthermore, the variety of tessellating tiles could be achieved by free movements of the points **M**, **E**, **F (**Figure 3**)**

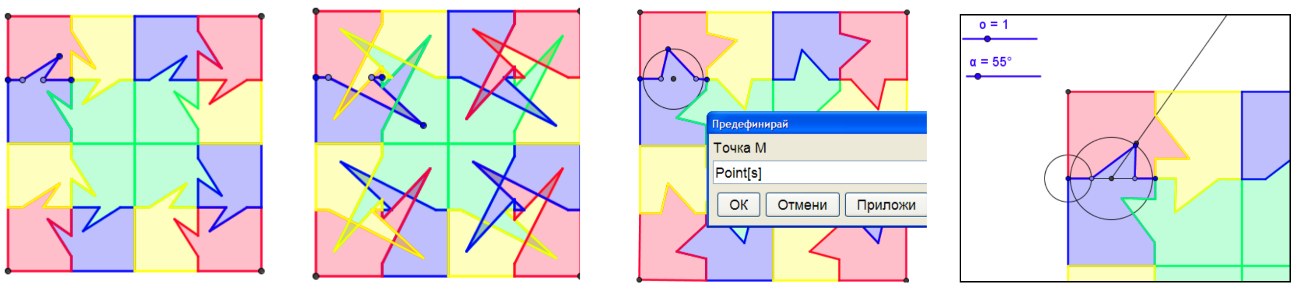

Figure 3. Variations by free movements of the points and a new construction to avoid self-intersection

Since **M** was chosen arbitrarily such a free movement would allow for self-intersection of the contour of the original tile (Figure 3 – the second picture) which contradicts to the idea of keeping its property of being a tessellating tile. To avoid this problem we shall choose point **M** on a preliminary constructed object, viz. a circle ***s*** with diameter close to (but smaller than) **AB**. We construct scrollers ***o*** and ***α*** to automise the movement of the points **E**, **F**. For the purpose we re-define point **E** as intersection point of the segment ***a*** = **AB** and a circle with center **A** and radius ***o*** (varied by the scroller ***o***). In order to be sure that such a point exists we fix **A** and **B** and assign an appropriate value for the upper boundary of ***o*** depending on the length of ***a*** = **AB**. Next we construct point **M** as intersection point of the circle ***s*** with the second leg of the angle with a vertex the midpoint of **AB**, a first leg passing through **B** and a measure in grades ***α*** (varied by the scroller ***α)*** . What is left is to hide the unnecessary elements and start the animation mode of the scrollers. These are only some of the ideas implemented in the context of the tessellation scenario but even they gave the impulse for working in exploratory style to teachers and students alike.

Playing Escher in a class setting

This scenario was presented (by the first two authors) with detailed instructions in a Bulgarian journal in mathematics and informatics. The third author (a teacher within the *Fibonacci* project) *took the gauntlet* and implemented it with 7-graders in IT classes. Here is what she shared at the bi-weekly seminar of the *Fibonacci* project: *The students started with the regular polygons tessellating the plane and followed the ideas of transforming a tile by means of dynamic constructions as presented in the scenario above. Soon they realised that they had discovered their own land for explorations – playing in the style of Escher by adding new points on the initial tessellating tile (square, triangle, hexagon, rhombus) and modifying them under various congruences so as to get beautiful tiling shapes – flowers, animals, traditional martenitsa' figures, small pieces of adornment, made of white and red yarn, and warn in March (Figure 6).*

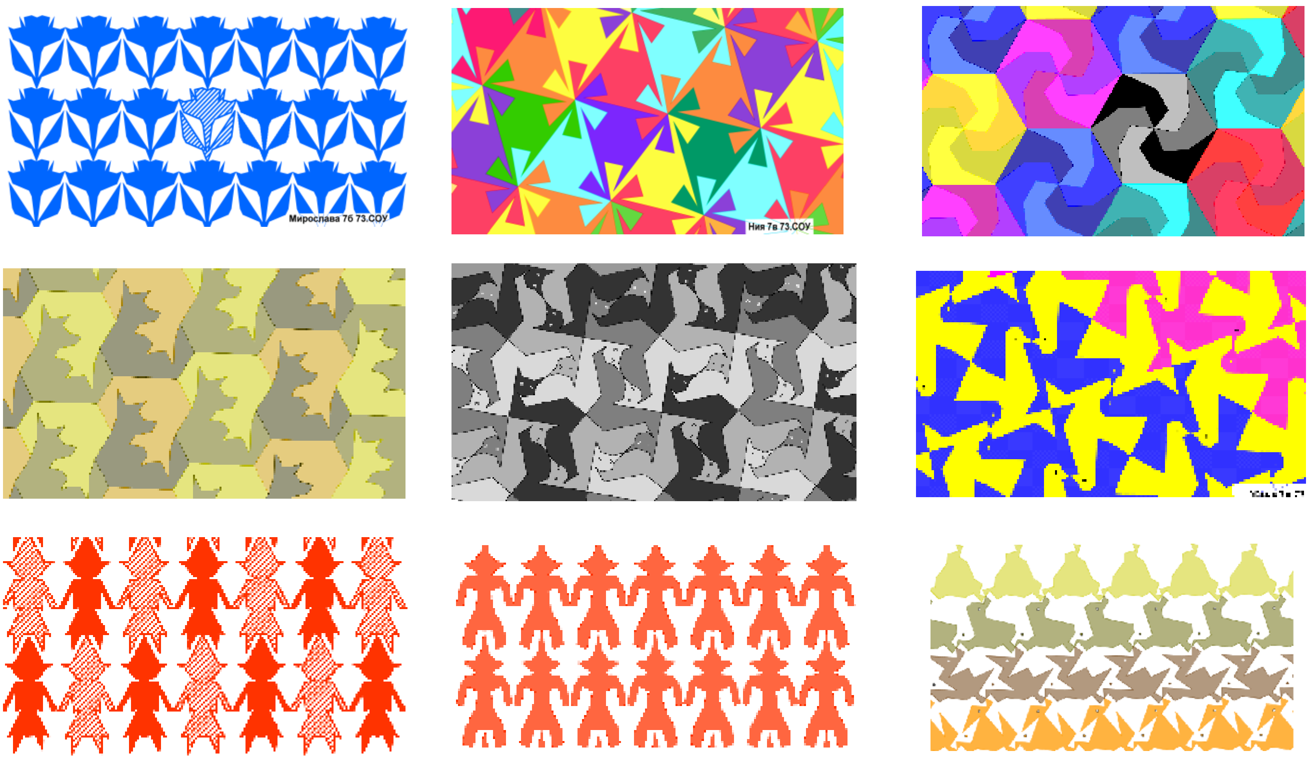

Figure 6. Students' esherizations – *flowers, animals, martenitsa's little people*

The truth is that the students discovered things that were new to me and we shared the joy. The temporary failures didn't discourage us. Sometimes we were looking for one thing and we *discovered another, or changed the direction of our explorations. It was with a great pleasure for me to realize that students who thought they didn't like mathematics all of a sudden became very active. In addition, I felt the support of colleagues the school management and the parents. As for our future plans, we already started a deeper inquiry on Escher and found that not only his tessellations but also his metamorphoses are inspirational. Here are their first attempts in this direction: (Figure 6 – bottom-right). The inquiry-based approach to learning bridged the usual generation gap between teachers and students – not only do they learn from us, but for sure we can learn a lot of new things from them and about them…*

Conclusion

The best works of the students were published on the *Fibonacc*i website and later presented in the form of book markers, greeting cards and framed paintings at a seminar within the *41st Spring Conference of the Union of Bulgarian Mathematicians* (Borovets, April 9-12, 2012). This was one more evidence that even within different computer environments the key factor for good learning outcomes is a didactic scenario tuned to the students' interests. Furthermore, we expect these outcomes to have a long-term effect since the students have worked in inquiry-based style and have *constructed a public entity*.

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EDUCATIONAL ROBOTICS IN One Laptop per Student – UCA Project

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Abstract

In one of the schools involved in the project One Laptop per Student-UCA in Campinas, SP, Brazil, the process of the teacher training involves the development of educational robotics activities. This involves conception, design and construction of robotic devices, using classmate laptop and development of methodologies integrated to the curriculum. Teacher training has been constituted as a research activity conducted by researchers at the Nucleus of Informatics Education Applied-NIED at State University of Campinas - UNICAMP. This article briefly presents the UCA program addressing their goals and processes for teacher education, discussions of educational robotics, objectives and methodologies of this research, partial results achieved and conclusions about this work.

Keywords

Educational Robotics, Teacher Education, Public School

Introduction

The project One Laptop per Student (UCA), of the Ministry of Education (MEC), Brazil, was developed by Núcleo de Informática Aplicada à Educação (NIED/UNICAMP) having as partners the Núcleo de Tecnologia Educacional (NTE) from Campinas and a municipal school in this city. In the State of São Paulo the UCA project is responsible for the preparation of local teams of teacher training in the use of low-cost classmate computer, integrated into the curriculum. Since 2010, the Educational Robotics at NIED has developed research in order to use the low-cost computer to control robotic devices whose purpose is educational and this activity is being applied by the Educational Robotics to a public school. The objective of this research is primarily to train the teachers for the use of Educational Robotics, with classmate computers as a tool able to enrich and contribute to the practice of teaching and learning in the classroom. The research discussed in this article only focus on a specific school from the process of training teachers of the project as a whole. So it was exclusively used on training teachers for the use of Educational Robotics at Elza Maria Pellegrini de Aguiar school. The methodology used is a qualitative study focusing on the development activities of teacher training for the use of robotics as a pedagogical resource. In this sense, the research emphasizes on monitoring the performance of these teachers with their students, in order to identify an effective contribution of this resource to enrich the curriculum in elementary school. As UCA Project is on implementation stage, the specific indicators about the improvement results from it to the curriculum are not read yet, though studies have been developed with this purpose. The article briefly presents this research on the implementation of robotics education in this school.

What is the Project One Computer per Student? – UCA

The UCA project began when the NGO One Laptop Per Child - OLPC was presented to the Brazilian government in the Economic World Forum in Davos - Switzerland, in January 2005. In June of that year, Nicholas Negroponte, Seymour Papert and Mary Lou Jepsen came to Brazil especially to exhibit this idea in detail. Over 2007 five schools were selected in five states. Since then 150,000 educational laptops were distributed to approximately 300 public schools. Each school received laptops for students and teachers, infrastructure for Internet access and training of managers and teachers in technology use. In 2010, the project was at the phase called “pilot”. This stage covered approximately 300 public schools, distributed in some units of the Brazilian Federation. In the city of Campinas, SP, training is held at the municipal school Elza Maria Pellegrini de Aguiar, which is the object of this research. In this context training fits the implementation process of educational robotics in that school and research activities involving students and school teachers. The figures 1 and 2 represent the low-cost computers of UCA program in Brazil.

Figure 1: Laptop Classmate

Figure 2: Laptop XO

Educational Robotics Environment

The educational robotics has been used for decades by educational institutions and researched as a tool to enrich teaching and learning environment. In this context it can be understood as a process of interaction with a robotic device (mechanical/electromechanical) and a way of promoting cognitive processes (d'Abreu & Garcia, 2010). Or,

> a *set of resources with the purpose of learning science and technology integrated into other areas of knowledge, using activities such as design, construction and programming of robot.* (Lopes, 2010, p.46).

Therefore, it is an interactive process seeking conciliation between concrete and abstract in solving a problem that involves steps such as: design, implementation, building automation and control mechanism. In all these steps can and should occur the construction of knowledge, coming from different scientific areas. An environment of educational robotics must bring to surface technological ideas and allow children to take ownership of them. In this context technological ideas were understood as the possibility of connecting mechanical parts and electronic components to perform a given task (Papert, 1994). Moreover, brings about the possibility of developing a teaching methodology in a rich and diverse way using low-cost computers. Studies are being made to enable the use of computers to perform activities of Educational Robotics with classmate computer involving the use of the software program scratch, (http://scratch.mit.edu/) low cost alternative material, and electronic interface with the Arduino (http://www.arduino.cc).

Contextualizing the research in the school

The research covers only part of the process of teacher training, in the UCA project, therefore, focuses exclusively on training teachers to use educational robotics at Elza Maria Pellegrini de Aguiar school. The study was developed in a public school which has approximately 500 students from 1st to 9th grade in elementary school. In 2011 two teachers and fifteen student monitors participated in these research. The group of 15 student monitors of different ages have learned to operate the computer classmate and begun to assist teachers in the task of appropriation and use of computers in the classroom for the educational robotics activities. The research was developed in a class of forty students. Despite the fact that each student has his/her computer, the educational robotic activities were developed in group. There were five groups of eight students each. There was not enough material for each student to develop his/her own project. For this and because working in a collaborative way emphasizes cooperation, the students were encouraged to work in groups. In addition, this team work also encourage exchanging and negotiation skills that are inherent aspects of the real situation of the society. By this classroom organization a rich learning situation provides Educational Robotics. The issue of the study was to understand "**what should be considered relevant in teacher training for implantation Educational Robotics in schools in terms of the UCA project?**"

Methodology of research

From the methodological point of view, the research began with the realization of pilot workshops conducted by researchers from NIED 2 teachers and 15 students in elementary school, students working as monitors. The workshops took place during two months in August and September 2011, at weekly meetings of two hours and 30 minutes, a total of 7 meetings, culminating with the participation of teachers and students monitors in the event "Arena Digital", figure 3a and 3b, promoted by the prefecture of the city of Campinas. During the second semester of 2011, in the development of the training process, teachers and students were extremely receptive, engaged and interested in working with Educational Robotics. The methodology involved the analysis of video recordings collected during the workshops. As interaction, meetings and conversations with teachers and with students were taking place, the importance of definitive establishment of educational robotics at school was becoming increasingly clear and welcome. Thus in the beginning of the year 2012, the final implementation phase of the Educational Robotics in school was established. In this phase the teachers were in the final stage of training and working with their students under the guidance of the researchers at NIED.

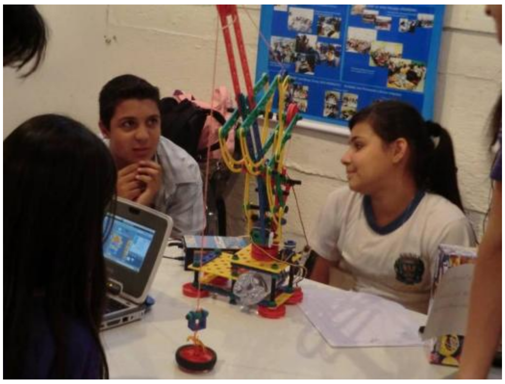

Figure 3a: Students operating a crane.

Figure 3b: Nightclub equipped with sensors that beep when the car enters

Considerations about the work

During the development of the training process, both, teachers and student monitors, were extremely receptive, interested and involved in the development of educational robotics in the school. Both have produced in the very first pilot workshops a blog (http://emefelza2010.blogspot.com/) on educational robotics. A teacher who worked with the student monitors, said:

> *"It was my first experience with robotics teaching and in fact, very positive, because I slowly got to realize that it must be used in an interdisciplinary way. In the workshops I could work the skills and abilities all the time ... Using laptop for performing the work is pretty easy, because it allows mobility, making it possible to develop collaborative projects ... It is something we were present to and is to be made part of our teaching process from now on ... "*

The following excerpt from the opinion of two student monitors who participated in the pilot workshops.

> *"Robotics taught many things I could not do through the computer. Robotics taught to program the robots using the computer. It also taught to work as a team. "Scratch" is a simple program that everyone could use. The time was very short, though. If there were more time, we could have learned much more "... "I loved the lessons I learned in robotics, mainly that the robots are moved by sensors ... We learn many interesting things in the robotics class."*

Partial results of the research

Developing activities in a context that integrates building robots, computer programming and electronics has enabled teachers and students from public schools to use ICT integrated to the curriculum in a context in which learning of scientific concepts happens differently. This proposal of teacher training its different from the others basically because of mobility it offers. Teachers and students can work with a laptop to develop activities inside or outside classroom, including at their houses. The role of student monitors to help teachers in the use of laptops in the classroom also constitutes a differentiated approach in which the teacher is no longer the absolute master of knowledge. He needs and so starts to accept the contribution of the student. An important fact to mention is that as a result of the workshops, the school board got to mobilize financial resources to purchase materials to build a room for Educational Robotics, what will enable the school to continue the project, incorporating it in its curriculum. This is denoted as a partial result which may become the improvement of teaching practice in school. It is worth mentioning as a partial result that from 2012 on students and teachers of public schools will be able to do science with the same standard of private schools with higher purchasing power. Making Educational Robotics in the context of the UCA project meant working in an environment which fed students to acquire skills like: design, construction, automation and control of robotic devices. This process allowed the practical use of math and physics concepts as force, velocity, acceleration, weight and so on. The students had a contextualized learning that allowed them to experiment, test and validate scientific hypotheses.

Conclusion

It can be affirmed in conclusion that the research basic issue was answered as he work was able to provide: studies on the possibilities of utilization of the classmate computer to perform activities of Pedagogical Robotics involving the use of the “scratch” and also alternative, low cost material; awareness of teachers and school board about the importance of working with Pedagogical Robotics in the formation process of didactic practice; ongoing development by the school board of actions aiming to final implementation of Pedagogical Robotics as curricular activity. The research is still going on, having the end due to the end of 2012, with the consolidation of teacher education. Records of video and audio of the research activities in 2012 will be analyzed and published later in other articles. It is hoped that from now to come a permanent and constant interaction of school teachers with the team of NIED is kept.

Acknowledgements

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Teaching how to teach how to teach programming

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Abstract

Over these last 12 years in Greece, a very large program has gradually been implemented whose aim is to integrate ICT into education generally, and into teaching practice specifically. Recently, Informatics and Computer Science teachers were also included. Training of teachers is an important part of this project – especially Informatics teachers. The preparation of trainers of these teachers "includes" necessary three distinct levels of interaction (preparation of trainers, training teachers, teaching of pupils) and thus it requires a negotiation on three distinct levels. Several important aspects of this preparation of trainers are examined and some findings, concerning the majors problems of this preparation, are examined. Our most important finding shows some aspects of the complexity of such a preparation program.

Keywords

Teaching Programming, Training Teachers, Transposition Didactique.

Introduction

Programming as a specific field of knowledge, balancing between art (Knuth, 1974) and science (Dijkstra, 1971; Dijkstra, 1976), between the demands of a rigorous branch of applied mathematics (Hoare, 1996) and the requirements of a profession, is a highly complex mental activity. Learning to program, even at an introductory level, seems to be difficult for young students: they usually do not understand the concepts of algorithms, data structures and programs and do not appear to be able to solve problems go beyond the ordinary or obvious.

As in other scientific fields, such as Mathematics or Physics, effective teaching requires specific course organization. The teacher should have specific knowledge and skills in order to not only recognize the difficulties encountered by students, but also to use possible methods for overcoming these difficulties, as well as to transform student misconceptions into other, more functional concepts. The teaching of programming, therefore, is a very demanding process. The teacher has to teach concepts whose "economy", i.e. function, cannot be understood in class. Students can, in the context of a programming course, for example, understand how an assignment or a selection structure in a given programming language works. However, it is much more difficult for them to understand why it is necessary to program in the context of specific *paradigms*, such as structured programming or object-oriented programming. The reasons for such a choice are of a scientific or economic nature, and these conditions cannot be reproduced in the classroom.

The basic elements that the preparation of teachers of programming should include are students' spontaneous perceptions and their standard errors, which will give teachers the knowledge needed to be able to deal with any difficulties the students encounter in the classroom; also course organization in order to maximize teaching efficiency and knowledge acquisition.

At another level, when preparing their courses, trainers instructing teachers not only have to be aware of the students' difficulties in solving programming problems (i.e. what the teachers should know), but also they need to be acquainted with any difficulties that the teachers themselves may encounter in teaching programming..

In this paper, as the title implies, we present a number of practices used in the preparation of trainers, In other words practices that are related to teaching trainers how to teach teachers how to teach students programming.

The "PAKE" schools

Over these last 12 years in Greece, a program has gradually been implemented whose aim is to integrate ICT into education generally, and into teaching practice specifically. Basically, the project involves K12 education in Greece. It is worth noting that within the context of this program seminars have been attended by about 120,000 teachers, some of whom have attended more than one (i.e., at different levels). This number represents approximately 65% of all active teachers (estimated total: 180,000) Recently, Informatics and Computer Science teachers were also included, making this a very significant program affecting the entire Greek education system.

The program has three levels of training/education: the first level corresponds to basic Computer skills, such as word processing or Internet navigation. The second level corresponds to specific training for teachers on how to use ICT in the classroom. At this second level, each scientific discipline (primary teachers, teachers of Mathematics, Physics etc) follows specialized courses in pedagogy and teaching using ICT. The third level corresponds to the training of trainers to teach at the second level. This takes place in training schools with the Greek acronym "PAKE". In Greek it stands for **PA**nepistimiaka **K**endra **E**kpedefsis, «*Πανεπιστημιακά Κέντρα Εκπαίδευσης*», meaning "University Centers for Educating (Trainers)".

These centers periodically operate as schools that prepare trainers, in other words, they are a very special kind of educational establishment where trainers of teachers are instructed by highly specialized educators. The following diagram may better explain the role of PAKE:

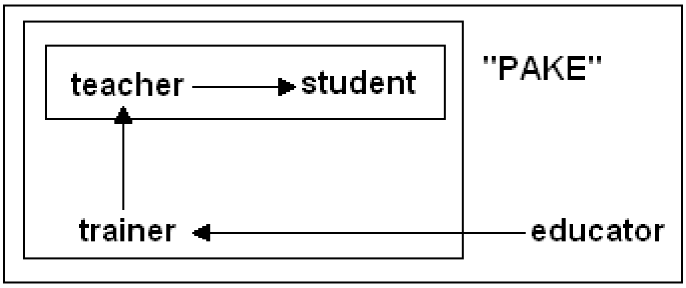

Figure 1. educating trainers in "PAKE". Each arrow means "educates"

Thus, training of trainers in PAKE requires a negotiation on three distinct levels:

- Level 1: teachers teach programming to students. Several research findings point out the difficulties faced by students when dealing with programming concepts and students' perceptions when attempting to solve problems. The concept of *teaching scenario* was created for the teaching of programming. A teaching scenario is a detailed description of a teaching module which can last more than one hour. Apart from the description of the learning objectives and the lesson itself, each teaching scenario includes information concerning classroom organization, the learning theories which the course is founded on, and when necessary, elements on epistemology. The teaching scenario attempts to provide a broad and in-depth analysis of the course that the teacher has prepared.

- Level 2: trainers instructing teachers. Besides the general principles of adult education, there are no substantial research on findings specifically on the training of Informatics and Computer Science teachers. The *training scenario* - similar to the teaching scenario- is the central idea of these courses. A training scenario describes in detail a unit (a piece of knowledge) which is taught to teachers. As is the case with the teaching scenario where a very important element is students' misconceptions of students, a significant part of the training scenarios make reference to the basic problems that may arise in the training of teachers. A characteristic problem is Greek teachers' awareness (or lack of) the necessity of such training. A typical response is: What can 144 training hours of seminars offer to teachers with 10-15 years of teaching experience? Teachers also tend to pose specific objections example, why they have to be trained in the teaching of Logo and Logo-like environments (such as Scratch and the Greek environment *Xelonokosmos*, the StarLogo and Turtle Art). The program tries_to include all the necessary elements in order to provide complete training to Informatics and Computer Science teachers.
- Level 3: training trainers (educators at PAKE instruct trainers). Few research data exist in this area – if any. In this case there is no particular scenario to follow, as is the case with levels 1 & 2 above, as the content and purpose of training trainers is too broad to fit into a single scenario model. A key element in the training of trainers was the distinction between levels 1 and 2. For instance, the trainers themselves many times questioned the need to actually create training seminars. The training of trainers does not only include preparing them to deal with new technologies that are known but have not yet been introduced in education - such as tablets and smartphones but also to prepare them for technologies that are completely unknown. How does one prepare trainers in technologies that are unknown? Among other things, certain recent changes in the Computer Science course at school, has resulted in added obstacles to training. In Greek schools, the interdisciplinary approach to the various subjects has recently been introduced along with a 'projects' approach (students work in groups on a specific project topic over the semester). Even in IT, there is an evident orientation to digital literacy or computers/information literacy. These changes are creating a new framework, a new "school ecology" in which the IT course is a part of. As is perhaps to be expected, these changes were not immediately accepted by all teachers thus compounding the task of training.

Examples, good practices, and some observations

The most important principles and applications of teaching practices that the trainers' training courses were based on are listed below.

- A comprehensive training curriculum that is versatile and <u>long term</u>. The duration of the curriculum of the participant trainers' course lasts over 380 hours covering many scientific fields and areas of knowledge. Thus, distance learning, synchronous and asynchronous (with environments such as Moodle platform and e-luminate) as well as issues related to the management of school laboratories and learning environments such as LAMS, are covered to a great extent. Besides technical skills, the trainers were also given an important theoretical base which included learning theories and teaching methodology, as well as issues related to adult education and modern theories about web 2.0 and Social Networking. What is termed the "General" section comprises an important component of the trainers' training. This section of the program is shared with other disciplines, such as Math or Physics in similar PAKE seminars. It should be noted here that some trainers disputed the need for such the general section in their training. Even though as a general principle it was accepted that there is common subject matter in different academic fields, such as learning theories or certain *didactic* phenomena (for example, incorrect or incomplete perceptions of students) which can be applied to various courses, nevertheless, trainers were sceptical about being taught subjects that were not, in their view, directly related to ICT.

- The training of trainers includes a very strong component of the Didactics of Informatics Theory and particularly that of computer programming. Apart from the basic concepts of teaching, such as a the concept of *didactic contract* and *transposition didactique*, this theoretical framework also includes research data related to concepts such as variables, the structure of repetition and choice teaching recursion, empirical research on the different programming environments and programming languages, algorithms, data structures, and other concepts. This approach enabled the differences in the construction of the teaching and training scenarios to be clearly seen, since the theoretical model of reciprocal interactions and observations of a teaching system (see Figure 1) clearly defines the framework within which these teaching interactions take place. The theoretical approach also contributed to the understanding of didactic material as *phenomena*, i.e. as observable events that are not random but are produced by causes and can thus be studied. Despite the fact that the trainee-trainers seem to understand and accept the Theory of the Didactics of Informatics and in particular of programming, it is not fully certain, however, whether they found all the didactic concepts taught useful. Especially in the early years, similar reservations were expressed in other fields, such as in the Didactics of Mathematics. Today, however, very little doubt remains as the Didactics of Mathematics is an established field of research in its own right.
- Practical experience constitutes a central factor in the training of trainers. The practical aspect of the course included the trainers having to observe both teaching and training classes. In addition, they had to create both teaching and training scenarios, and then implement their teaching. Each trainer had to first teach students at a school and then teach teachers at an in-service seminar. At all times a PAKE supervisor provided assistance and guidance during these practicals. The subject matter that was taught was decided by both the supervisor and trainee-trainer. Furthermore, all the observations and instructions were carefully designed with the supervisor's help. On completion of the practical, the trainee-trainers were required to submit a detailed report that was discussed by all the participants.
- In addition to becoming familiar with environments such as Moodle, platform e-luminate, LAMS and the like, participants are also taught to create teaching and training scenarios both for concepts related to various programming paradigms and different languages and environments. Their training includes theory and exercises related to teaching structured programming, object-oriented programming and functional programming (Logo-like style). These three options in some way correspond to the three different orientations for the teaching of programming in Greek schools: (i) programming as part of a broader informatics fluency (mainly in the first 9 years); (ii) programming as a preparatory course for high schools (structured); (iii) programming as a job qualification (object-oriented, mainly in vocational schools). The respective languages are Logo-like languages, and those for object-oriented and structured programming. In most cases, the software used has many options

which can support novices in learning programming concepts: they one to see, to some extent, the execution of the programs; they have structure editors, friendly interface and messages with precise content and clear meaning. Programming concepts are also taught indirectly in other environments, such as spreadsheets.

- The system for the evaluation of trainee-trainers includes both a formative and final evaluation Participants are required to several essays and reports throughout the program (16 in total) that vary in content and size. They are also required to participate in forae, create (and update) blogs, to upload their work in e-portfolio (Mahara), and generally to take part in a series of activities of a digital nature that are in some way related to the training program they will undertake on completion and certification. They then must sit a final test, which includes a series of closed-type multiple choice questions, and the like. However, the section of the examination that is worth the most marks is an essay of a training scenario (that includes a teaching scenario) on a particular concept or method. Throughout the PAKE course participants prepare, present, comment on dozens of both teaching and training scenarios, with the objective to become familiar with this particular way of working.
- In addition to items directly related to the teaching of Informatics generally and programming in particular, participants are also taught a number of subjects that are essential, or simply useful for their training, such as techniques in adult education.

Comments and conclusions

The PAKE training program has provided numerous qualitative and quantitative data enabling us to reach some initial conclusions.

A point worth mentioning relates to the deeper understanding of mainly theoretical concepts, that the participating trainee-trainers acquire. For example, constructivism is a widespread theory of learning that supports multiple teaching methods. However, in many cases, the constant reference to constructivism in the participants' scenarios seems to be more of a routine procedure, rather than the outcome of thorough analysis and choice. This phenomenon was also observed in other cases. For instance, the constant reference to scenarios of particular theoretical views and generally accepted assumptions integrated into the dominant paradigm, at times appears to be more the result of an "alignment" with the paradigm, rather than an informed choice. It is often the case that theoretical concepts, especially when not accompanied by a significant number of concrete examples, are totally misunderstood by participants.

The integration of programming into the school curriculum requires a specific transposition didactique: scientific knowledge and professional practice is transferred to the school and included in the educational context. Thus, the concepts are simplified to make them more easily understood; the course is organized into 45-50-minute sessions, which is the duration of a teaching period in Greek schools; the subject matter has been organized into introductory units, exercises, questions, problems. However, during this transposition of concepts into the school environment, another transformation takes place: namely, the scolarization of an entire scientific field favors certain types of problems, while marginalizing other aspects of the key concepts, such as algorithms, data structures, and programming generally. For example, data structures as a means of encoding entities of the external world, such as images, text, etc., are rarely referred to in the school environment. Trainee-trainers in many cases, did not fully acknowledge the importance of teaching or the activities on such issues, considering them of no use, since they were not directly related to current concepts of programming – at least the "school version" of programming.

Due to the fact that this program was implemented for Informatics and Computer Science for the first time in 2011, the data thus far do not allow us to evaluate further the effectiveness of the training that the participant trainee-trainers underwent. Subsequent phases of the training program, we hope will provide more in-depth information on this issue.

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Constructionist learning of geometry

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Abstract

This paper deals with a constructionist learning approach to geometry and particularly with dynamic geometry software. A theoretical framework of constructionism and its connection with geometry education is discussed. Dynamic geometry education is important for pupils to develop visualisation and spatial thinking. The reasons of usage difficulties of dynamic geometry and the way how to help mathematics teachers to use digital tools for constructionist learning are presented. The main attention is paid to the constructionist learning model for learning geometry developed by Baytak (2011). The model is extended and adapted for teaching geometry at a lower and upper secondary school level. The new features of learning and teaching mathematics are discussed. Finally, interactive books for teaching mathematics in secondary schools are presented and discussed. The example of practical usage of pre-created interactive sketch is presented.

Keywords

Constructionist learning, learning by doing, mathematics education, dynamic geometry

Introduction

"Constructionism shares constructivism's view of learning as building knowledge structures through progressive internalization of actions... It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" (Papert, 1991, p. 1)

Seymour Papert launched the idea of constructionism more than a quarter of a century ago. The latter idea inspires to develop a theory of pedagogy that could foster learning. It is more than a methodology, seeking to develop knowledge structures in the mind of a child alongside physical or virtual structures external to the mind. Understanding the development of the structure of knowledge is part of a powerful pedagogic theory and practice. Constructionism is about the ways that human beings come to learn most effectively; building, debugging, sharing in ways that could at last be reasonably straightforward thanks to digital technologies.

Constructionism increasingly struggles into many areas of education. Mathematics, particularly geometry, is one of the most appropriate subjects for realizing constructionist ideas because geometry itself plays with objects and requires constructing them. This shows that learning geometry can be grounded by the constructive theory and based on teachers' interaction ways to constructionist learning. We analyse the influence of the interactive tool on the teacher's traditional methods of teaching, trying to answer a question how to help the traditional teacher to integrate digital tools and support the constructionist learning. We have extended and adapted the constructionist learning model to geometry developed by Baytak (2011).

The new psychological tendency and development of information technologies have affected the development of new technological tools to be used for active teaching and learning methods. The first ideas of constructionism based on information technology in education have been spread by S. Papert. He was one of the first who looked at a child as a creator (Papert, 1993). Most of the follow-up educational software developers relied on the S. Papert ideas and methodologies (Hay, Barabbas, 2001). We have argued that dynamic geometry software realizes constructionist ideas as it enforces a constructive approach.

Constructionist ideas can be effectively realized in mathematics education. However, it is still a strong focus on mathematical knowledge acquisition in Lithuania (Dagienë et al., 2007). Teachers are not prepared to accept a new view of mathematics education. After literature studies, we have found some reasons why most math teachers do not accept constructionist ideas (Hohenwarter et al. 2009; Stols et al., 2011). These studies have inspired some ideas: to develop some approach how to make mathematics studies easier for both students and teachers. The developed approach links together a traditional way of teaching mathematics with the facilities of new media. So, we have not to enforce traditional teachers for quick changes, but to offer them our help by developing flexible interactive tools with dynamic geometry which supported the mathematics curriculum. These tools allow appearing of the new features of learning and teaching mathematics: interactive sketches open way of new geometric visualisation and mathematical thinking, the students become active researches and developers, the creation of dynamic sketches develop students' creativeness and deeper understanding of geometry and relation between geometry and algebra.

The developed interactive tool requires a new constructionist learning approach to mathematics education. We have proposed a model for learning mathematics with dynamic geometry in this paper. The proposed model is based on the Baytak (2011) model in combination with Kolb's (2005) learning cycle.

The developed interactive tool is created using the dynamic geometry software, namely Geometer's Sketchpad (http://www.dynamicgeometry.com/). This program has been chosen for several reasons: first, it has been implemented in Lithuanian schools (it is localized, teachers are trained to use the program, materials for teachers training are prepared); second, Geometer's Sketchpad is able to create interactive books with dynamic sketches (using the same program without any additional program) and third, Geometer's Sketchpad sketches are based on the hierarchy of objects. Also there is possibility to create scripts and additional tools (Jackiw, 1993).

Theoretical framework

Constructionist learning

Education is affected by various psychological theories. For many years the training has been based on the ideas of behaviourism and focuses on the accumulation of knowledge, teaching lectures, and reflection. At the same time, other psychological tendencies have been developed, i.e. a cognitive theory which has changed the approach to teaching. Teaching ideas based on the collection, processing, development, attention is directed to thinking. Basically in both directions the teacher's and student's role is different: in the first one the teacher is a trainer and information provider, and the student is the receiver of information, in the second one the teacher is an advisor and the student is the information gatherer, handler and developer (Hubwieser, 2000).

The mathematics teaching was influenced by these two psychological theories. Therefore, the present-day mathematics teachers use quite a comfortable method which does not require a lot of preparation for teaching – lecture. Or otherwise, the teacher integrates cognitive ideas, methods, based on looking at the student as a thinking person: discussions, problem solving, and collaboration. Thus, both behavioural and cognitive methods of training are adequate when they match teaching and learning goals.

With an increasing number of information contents, the man just could not remember a superfluity of information. Thus, Jean Piaget's psychology-based training – constructivism – was used. The main principle of this theory is experience-based knowledge creation, where the learner is actively involved in teaching and learning. When shifting from teaching to learning, it means that the whole educational process focuses on learning, on new tools that encourage everybody to learn successfully and be motivated. The teacher becomes a counsellor who helps to strengthen the links between different areas of education.

Constructivist learning emphasizes the following ideas: 1) the children are developers of their own knowledge and external realities; 2) knowledge of the world is constructed and interpreted by using certain tools and symbols.

Seymour Papert (1993) looked deeper and wrote that it was important how children learn in a particular context, using their own and other's created objects and he focused on the role of ICT in human learning. The new learning theory – constructionism – has begun, where the main point is to learn different methods and ways of purposeful information to select and absorb the abundance of knowledge, and using them effectively, to create new knowledge. A few years later, S. Papert (1999) outlined eight big ideas of constructionist learning: (1) learning by doing – students learn better when learning is part of doing something what is interesting; (2) technology as the building material – things can be made more interesting; (3) hard fun – to enjoy what you are doing; (4) learning to learn – student has to take charge of his own learning; (5) taking time – the proper time of the job – student have to learn to manage time himself; (6) you cannot get it right without getting it wrong – to goof in the way is nothing wrong; (7) do unto ourselves what we do unto students – to let students see us struggle to learn; (8) digital world – using computers to learn about everything.

A well known percentage of realized information using various teaching methods allows us look at the difference of effectiveness of teaching methods from a lecture to teach others (Brooks, 1993). The constructionist background of teaching methods is practice by doing and even 75% information is realized using these methods.

Other constructionist Richard Noss (2010) has presented features of constructionist learning: sharing, personalization, making learnable what is unlearnable, making visible what is invisible, and mastery. Baytak argues that the constructionist learning consists of two steps: the internal step – learning is an active process when students construct their knowledge from their experiences, and the external one, which is based on the research which suggests that students learn best by making artefacts that can be shared with others (Baytak, 2011). The internal step derives from constructivism, the external step relates to the constructionism.

Dynamic geometry and constructionism

The new psychological tendency and development of information technologies have affected the development of new technological tools for using active teaching and learning methods. The first ideas of constructionism based on information technology in education have been spread by S.Papert as mentioned above. He is the creator of the education technology, based on the constructionist idea – learning by doing. Most of the follow-up educational software is grounded by S. Papert ideas and methodologies (Hay, Barabbas, 2001).

One of such software is the dynamic geometry for teaching and learning mathematics. There are plenty of definitions of dynamic geometry, but they emphasize that the dynamic geometry is a technological tool that allows users to construct directly associated geometric objects of mathematical phenomena, that can be transformed and explored using a variety of technological and computerized management tools, and to hold relationships between designed objects at the same time. Most of the dynamic geometry software allows us to draw and construct Euclidean geometry objects and to transform (move, rotate, stretch or reflect) them, such as additional tools to animate drawings, to draw graphs of functions on the Cartesian or polar coordinates, write equations of straight lines and circles, to measure the geometric object by selected measurement units to perform various arithmetic operations, supplemented by drawings of the inscriptions, to write the mathematical text (Jasutė & Dagienė, 2011). Often such a constructed sketch is called as a dynamic or interactive image.

The fundamental of the dynamic geometry development bear a didactic idea to construct student's knowledge by investigating geometric objects and relationships between them (Jackiw, 2004). Scientists improved the dynamic geometry influence on deductive thinking, mathematical thinking, mathematical imagination, geometric perception (Jones, 2000; Patsiomitou et al., 2008). Thus, learning by constructing is the main principle of dynamic geometry, and it can be realized so that the dynamic geometry implements all S. Papert's constructionist learning ideas, mentioned in the introduction. Especially learning by doing is the basic idea of dynamic geometry software.

Following R. Noss (2010), the dynamic geometry enables us to personalize geometry learning: 1) each student can learn at his own rate, use his experience; 2) creation and pre-created sketches can be used for every learning style of Kolb's experiential learning cycle (active hypotheses, active testing, concrete experience and reflective observation). Kolb's learning cycle lies in the educational background of the dynamic geometry.

The fundamental idea of dynamic geometry lies in the idea of constructionism: students are learning by their own experience and sharing with others. The dynamic geometry is constructed for teaching and learning geometry (and sometimes for algebra) in such a way that it helps to use various methods of teaching and learning, to make the teaching process more attractive, and to learn geometry deeper. The dynamic geometry is designed so that the student is actively involved in the design and study.

Constructionist learning environment

Constructionist learning model of mathematics using the dynamic geometry

One of the well-known approaches to up to date learning geometry is presented by A. Baytak (2011). We have chosen the model and adapted it for learning mathematics using the dynamic geometry.

A. Baytak (2011) presents the model of constructionist learning, where he declares four steps: planning, designing, testing, and sharing. His model is constructed for learning by game design (Baytak, 2011). Internal learning and external learning have been distinguished. He ascribes the internal learning to constructivism and the external learning to constructionism.

When learning using the dynamic geometry, the design step is changed by developing a drawing scenario, and testing is changed by drawings. Other steps are left the same. The grey part outside the schema (Figure 1) is the Baytak model, and the black part is an extended model adapted for geometry learning using the dynamic geometry.

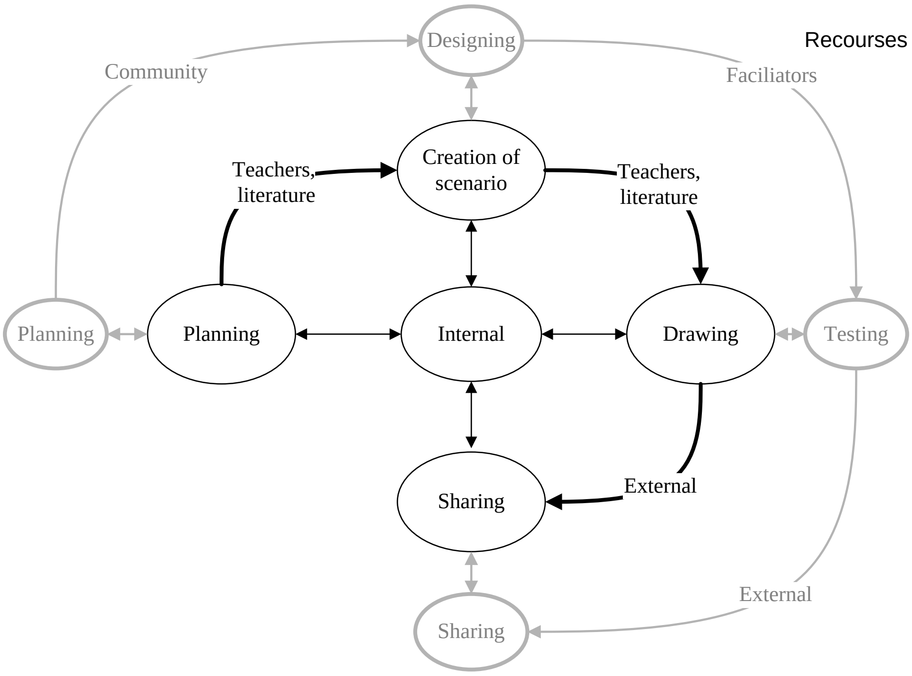

Figure 1.Model of the constructionist learning of geometry (the extended and adapted Baytak model).

In this model, a student is an active creator who shares his created sketch with other students. In this model, four stages for the student are seen: 1) planning – to get his task and start to plan how to realize it; all resources and teacher's instructions can be used; 2) creation of its scenario – to think about the scenario how to draw a sketch (steps of drawing) – the algorithm how to draw a geometric object with pair of compasses and a ruler must be developed, the knowledge of geometry and the usage of dynamic geometry software are needed in this stage; 3) drawing – to create a drawing and test it by dragging free objects to verify whether the drawing is correct, and 4) sharing – to present and explain the drawing to other students; it can be discussed from the way how it has been created and how geometric correctness has been proved.

We used Kolb's (2005) experiential learning cycle to explain our view of constructionist learning mathematics using the dynamic geometry. Kolb's learning cycle is for experiential learning. Learning by dynamic geometry is based on students' experience and practice. There are four stages in the experiential learning cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. These stages are related with four learning styles: diverging, assimilating, converging, and accommodating. These relations are seen in Table 1.

	Active experimentation	Reflective observation
Concrete experience	Accommodating	Diverging
Abstract conceptualization	Converging	Assimilation

Table 1. Kolb's learning styles

Usually there are students with several learning styles in the class. Thus, a teacher has to prepare the material for all the learning styles for a lesson. In this case, we are interested in Kolb's cycle learning stages for mathematics learning to make the learning process more effective, to involve most students in the class. To this end we have extended the model of geometry related to Kolb's learning cycle stages (Figure 2).

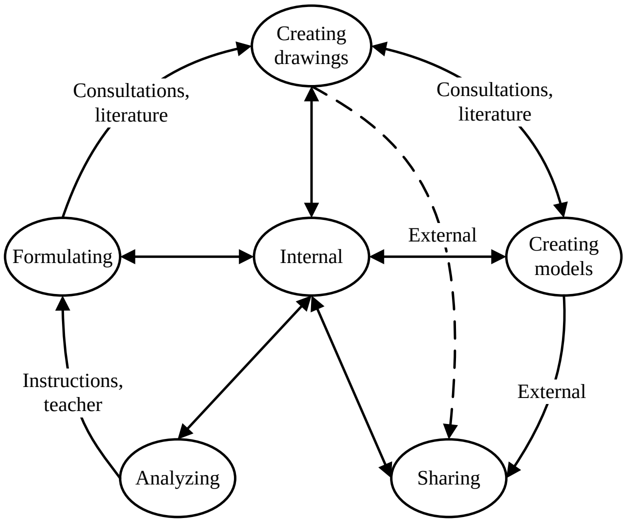

Figure 2. The Extended Constructionist learning model

The model illustrates five steps of learning: 1) analyzing – a student moves free geometric objects in the pre-created sketch and observes what is moving, changing, what properties remain the same, etc.; 2) formulating – a student formulates concepts, properties, axioms, theorems according to his experience of dynamic drawings; 3) creating a drawing – when a student analyzes the drawing and gets some knowledge by his experience, he can create some drawing himself by the steps which have been described in Figure 2; 4) a student shares and discusses his drawing with other students; 5) creating models – here we mean that a student has to creates a model (plan, tile, etc.) of a realistic object (box, furniture, room, yard etc.) using dynamic geometry and he shares it, discusses his drawing with other students. In all steps the student constructs his own internal knowledge by interactions with the external learning environment (teachers, students, literature, internet etc.). The whole process is associated with the information technology (in our case, dynamic geometry software, internet explorer). These steps are new trend in teaching and learning mathematics. The student is involved in active process and interactive sketches open way of new geometric visualisation and mathematical thinking.

All five steps are related to Kolb's learning stages as shown in Table 2.

	Active experimentation	Reflective observation
Concrete experience	Share	Analyze, formulate
Abstract conceptualization	Drawing	Model

Table 2. Relation of the learning steps to Kolb's stages

Comparing Tables 1 and 2, each step of the model is attached to one of Kolb's learning styles: analyzing and formulating to diverging; drawing to converging; creating models to assimilating and share to accommodating.

The developed model can be useful for teachers to prepare lessons. It probably can help to analyze the learning or teaching material and to think how to adapt it to different learners and to use constructionist mathematics learning. The first two steps of the model are adjusted for mathematics learning with dynamic geometry in this paper. The others steps requires more detailed studies.

Reason of creating pre-constructed sketches

Constructionist ideas can be effectively realized in mathematics lessons. However, there is still a strong focus on mathematical knowledge acquisition in Lithuania (Dagienė et al., 2007). Therefore constructionist ideas are integrated into the teaching of mathematics very slowly because teachers have to adapt to the new environment. Most of them have to spend more time for preparing. Teaching mathematics is mostly based on an academic approach – it is intended for the national school – leaving mathematics exam obligatory for almost every higher school. In view of that, the majority of our mathematics teachers can be considered as traditional teachers.

Some more reasons, why mathematics teachers do not use constructionist learning tools, i.e. dynamic geometry in their lessons, have been found by analyzing literature:

- The lack of the skills in information technology has an impact on the use of dynamic geometry for most teachers (Stols, Kriek, 2011).
- The dynamic geometry is relatively complex for a math teacher for several reasons: first, a dynamic geometry construction is based on a hierarchy and to construct a sketch, teachers must have (or acquire) new skills of developing algorithms and programming by geometry; second, most tools of dynamic geometry software are rather complex for the teacher (Hohenwarter et al. 2009).
- Some scientists see quite the other problem of information technology. They argue that the usage of digital tools depends on the teacher's disposition. If the teacher uses active learning and constructive methods of teaching, he/she is willing to use the dynamic geometry for teaching, if the teacher uses traditional teaching methods, he/she is not willing to use information technologies for teaching (Stols, Kriek, 2011).

While there are some problems of using the dynamic geometry, the software can help teachers to use a variety of constructionist teaching and learning methods. Four guided methods are defined for teaching mathematics with dynamic geometry which are related more or less with the ideas of construcionism: 1) a student is constructing dynamic sketches himself by his experience; 2) a student is analyzing individually geometric concepts and properties of geometric objects in the pre-created dynamic sketches with some instructions and directed questions; 3) a student is analyzing pre-created dynamic sketches with the teacher in the class, if the teacher uses the dynamic sketch to illustrate the explanation of geometry and 4) a student is learning by a pre-created book of dynamic sketches, when he has all the sketches that consistently illustrate all the topics of geometry and can analyze them individually (Dagienë & Jasutiene, 2007). All the learning methods described can be used with the model presented in Figure 2.

These studies have inspired the ideas how to develop an approach making the mathematics studies easier for both students and teachers. The developed approach links together a traditional way of teaching mathematics with the facilities of uptodate media. Thus, we are not going to force teachers for quick changes, vice versa we offer them support by developing flexible interactive tools for dynamic geometry.

Interactive book with dynamic geometry

In order to find an effective and quick solution the educational mathematics program has been reviewed and dynamic drawings sets have been created for 9th and 10th grades (Dagienë, Jasutiene, 2006). More than 500 dynamic sketches have been created and put in the interactive book which makes it easier for teachers to prepare for mathematics lessons. The interactive books include a user-assistance, research directions and theoretical insertion, and additional tasks.

The interactive book can be used at classes in different ways: as the aids; students can explore drawings independently after lessons: students can use it while working individually and collectively; a teacher can to demonstrate and explain the topics of geometry much easier with the help of the interactive book. As shown in practice, the students like it more, when they can change a drawing and look what happens. Students feel then as researchers.

The interactive books compel teachers to think in advance what, when and how to present to students. For example, in the classroom with multimedia projector pre-created sketches can be used for a few minutes to illustrate one or more dynamic drawings.

If students are taught in the computer classroom and they are exploring drawing themselves, it is important to formulate the goals what teacher would like to teach, to prepare purposive questions for students, to which they seek answers and formulate their own concepts or draw conclusions. Such lessons in the computer classroom are very useful, because the opportunity for students to press the buttons themselves, discover themselves and to detect patterns, being moved by curiosity, to formulate their own questions and find their own answers of a great value.

It would be great, if students could use the interactive books in the lessons and after them. Then the teacher can give students a brief individual task or, over a longer period of time, a group task. The tasks can be related to the theoretical material and the textbook of the task.

Only some possible scenarios of teaching and learning with interactive book are reviewed in this paper. The innovative teacher can offer much more methods for effective mathematics learning and teaching in the class. The interactive book is used for first two steps of the Extended Constructionist learning model of learning mathematics.

The example of practical usage of pre-created dynamic sketch

An example of the usage of dynamic sketches is presented. It illustrates the possible way of learning of 10th grade topic “The function $f(x) = ax^3$”. According to the Lithuanian national mathematics curriculum a student should to recognise graph of the function, to draw graph of the function, to calculate values of the function when learning this topic.

For this topic one dynamic sketch have been developed (Figure 3). It has been created considering the student skills what have to be developed by national curriculum. This sketch can be analyzed in four stages:

- When student opens sketch he gets graph of function $f(x) = ax^3$ with additional buttons on the screen. The student can change parameter a by pressing button “Change a” and look how the graph of the function is changing. He can notice how graph of function $f(x) = ax^3$ look and where it is plotted when parameter is negative or positive number etc. From the other hand he can move point x on the axis and look what value function gets.
- When student presses button “Show table” he gets additional information – table of values of function. He can analyze values of the function in the table. The student can change parameter a and look what happen with the values in the table.
- When student presses buttons “Show $y=x^3$” and “Show $y=-x^3$” the two more graphs are plotted in the coordinate system and two additional lines appear in the table of the values. The student can compare three graphs and values of all three functions.
- When student presses button “Show conclusion” the some theoretical statements appear. The student can test himself if his acquired skills are correct.

While some instructions and additional tasks are given in the interactive book with this sketch it is recommended the teacher to prepare consistent questions, instructions or worksheets for students' independent or group work. Practice shows that these instructions help students to concentrate on acquiring correct skills which have to be developed.

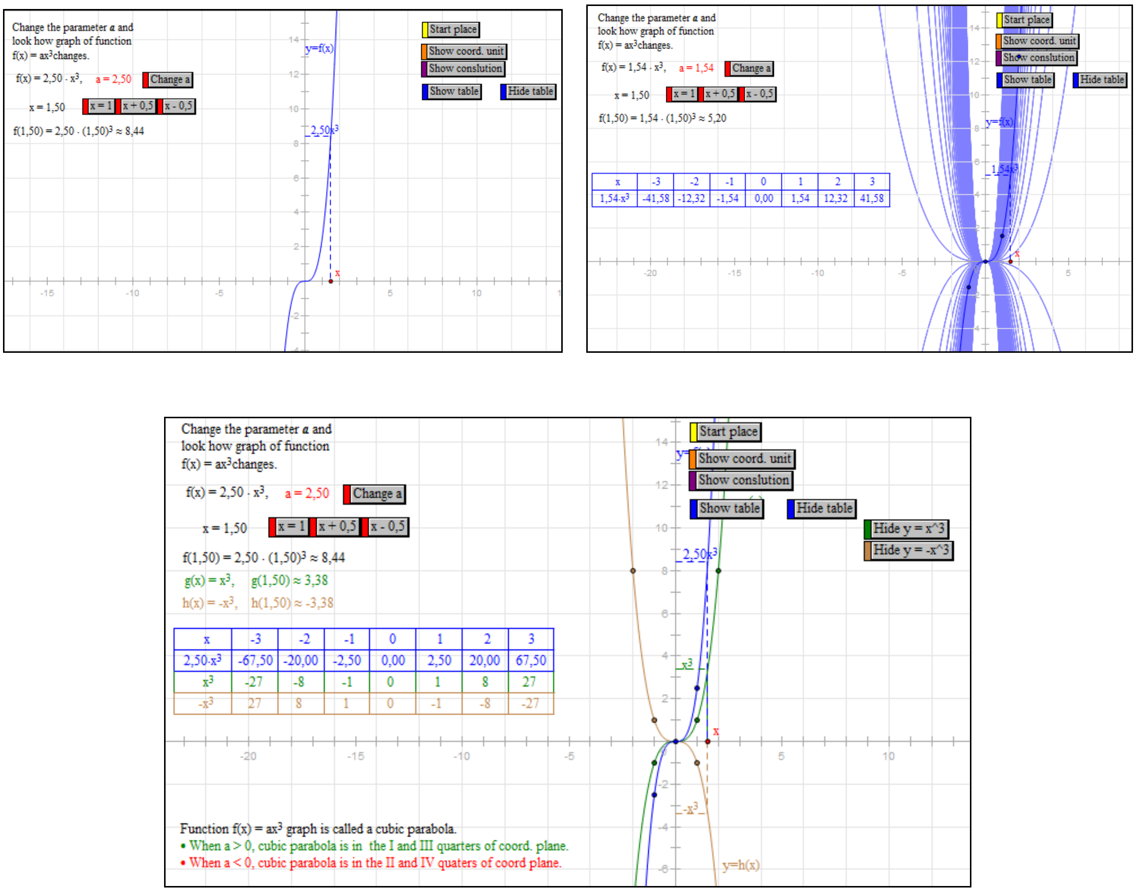

Figure 3. Example of the investigation of function f(x) = ax³ with the interactive book for 10th grade.

The analysing of such pre-created sketches has more potency than teaching with traditional methods for some reasons:

- When the function $f(x) = ax^3$ is investigated in the class, only few examples of such function can be provided in the textbook, notebook, or on the board. With an interactive book, in a few minutes all the properties of function $f(x) = ax^3$ and changes in the graph can be easily seen (Figure 3).
- This sketch illustrates relationship between the graph and the expression of its function directly. This skill is not mentioned in the curricula, but it is hidden under the calculation of values of the function.
- The students are active researches in this process ant it is more important feature in the constructivist learning.
- Pre-created sketches do not require additional teachers' skills and can be easily adjusted for class.

This example illustrates only one possible scenario of a lesson when student actively analyzes sketch. This sketch can be used in the teaching scenarios which where discussed above and can be creatively used in other scenarios.

Conclusions

The information technology opens a way to constructionist learning in mathematics. Using the information technology in the classroom, a teacher has to change the traditional approach to teaching and learning methods. In order to achieve better learning and relationships with students, the teacher has to apply innovative approaches or to integrate them into traditional ones.

We have extended and adapted constructionist learning model for geometry learning using the dynamic geometry. This model allowed us to conceive constructionist learning of mathematics more clearly. A student who has passed all the steps of the model, gains deeper understanding of the real world and relations of algebra with geometry, which is very important for student's mathematical thinking and learning motivation. However, these statements must be proved by some experiments in the future.

The computer program Geometer's Sketchpad and created dynamic sets of drawings "Mathematics with Dynamic Geometry" for the 9th and 10th grades are appropriate for mathematics education by constructionist ideas. The student is an active learner and the teacher becomes a counsellor and consultant for the student when dynamic geometry is used. In addition, the student can use dynamic sketches independently of the teacher and his IT competence, because interactive books have user support, advice, and theoretical insertion. In this case, the teacher can only give advice to students about mathematical issues (what he is doing in the traditional math classes).

The presented model and interactive tool open new tend to mathematics education. The student become active researcher and developer and the teacher become adviser for student. The pre-created interactive sketches deliver new view of geometry visualizations: with an interactive sketch all the properties of the geometric or algebraic objects can be investigated in a few minutes whereas the traditional methods allow investigating of few examples of such objects provided in the textbook, notebook, or on the board.

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Design Compass: Facilitating metacognition in construction activities in K-16 classrooms

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Abstract

Design Compass is an educational tool designed to facilitate learners' metacognitive thinking during construction activities. Learners record their progress through the engineering design process by selecting the appropriate step in the Design Compass, which tracks the amount of time spent on each step and presents this data to the learner in the form of a histogram. A study was conducted to evaluate the usability of the Design Compass. Participants recorded their process in the Design Compass while working on a construction activity. Results suggest that the Compass is easy to pick up and use and leads to more reflective thinking, but does not capture multitasking by individuals or groups. Further revisions to the Design Compass are discussed.

Keywords

Engineering, metacognition, constructionism

Introduction: Constructionism

Constructionism can be thought of as "learning-by-making" (Papert, 1980). Through the physical creation of artifacts, learners engage with science content in a meaningful and authentic way. Infusing hands-on construction activities into engineering curriculum can increase learning and retention (Ortiz, 2010). The process of manipulating materials in an effort to create artifacts provides opportunities for engaging and motivating learners (Kolodner & Nagel, 1999).

In a typical construction activity, learners have limited opportunities to reflect on their process. When learners are asked to describe what they did at the completion of the activity, they often struggle with accurately recalling what they did during the activity (Crismond & Atman, in press). Some curriculum designers combat this by scaffolding the design process for students (e.g., Learning By Design, Engineering is Elementary); however, the majority of these efforts dictate the process to the students rather than allow them to identify, on their own, how they engage in the process. This bucks the constructionist philosophy that aims to have students engage in personally meaningful exercises rather than rote, pre-determined processes.

There is a missed opportunity here to infuse metacognition into constructionist activities. Metacognition is the monitoring of one's own thinking (Flavell, 1979). Influsing metacognitive opportunities into the design process allows students to reflect, debug and systematize their processes, and is associated with the production of higher-quality products (Adams & Atman, 2000).

The Design Compass as a Constructionist Tool

Design Compass is an educational tool that allows users to track their progress through the engineering design process while working on a construction activity (Crismond, Hynes, & Danahy, 2010).

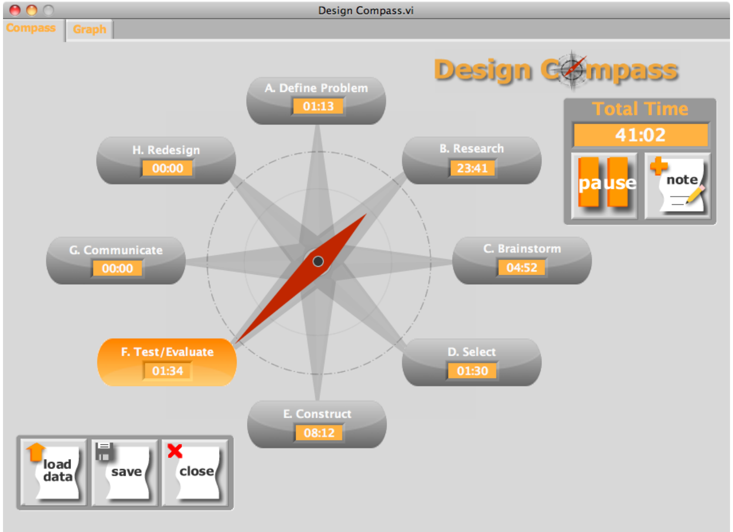

Figure 1. Compass (Main View) of the Design Compass

The main screen, shown in Figure 1, contains a timer that keeps track of the total time, as well as the steps of the engineering design process (i.e. define problem, brainstorm, research, etc.) (Massachusetts DOE, 2006). When a step is selected, the red arrow of the compass points to that selected step, and a timer associated with that step begins to keep time. Users are also able record notes and upload images.

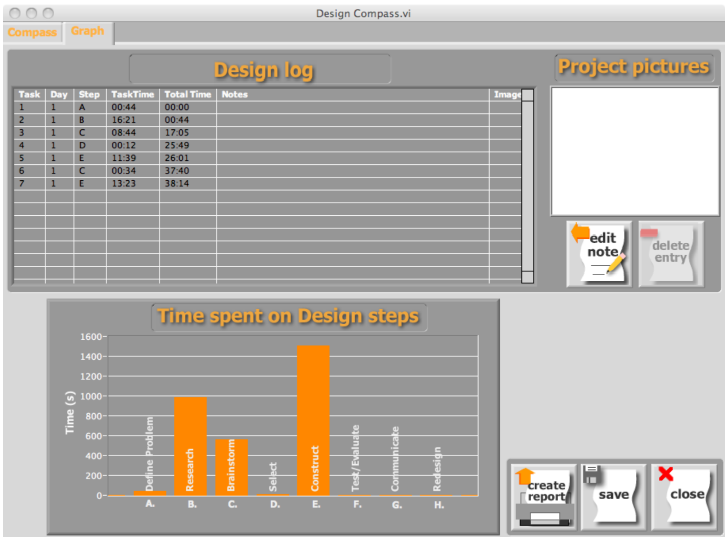

Figure 2. Data View of the Design Compass

The graph view displays a table with cumulative data about the order of the steps and the time spent in each in step. Data from the table is summarized in a histogram, which allows users to compare the amount of time spent on each of the steps.

While learners work through an activity, they are challenged to think actively about what step of the design process they are on in order to report this in the Compass, as well as presented with opportunities to capture their process in notes and images. After completing the activity, learners are able to reflect using quantitative data.

Method

A study of the Design Compass was conducted with five undergraduate students from various engineering disciplines. The participants used the Design Compass while completing a constructionist activity in which they needed to build a prototype of a one-handed jar opener using LEGO bricks (Lemons, Carberry, Swan, Jarvin, & Rogers, 2010). Participants had seventy-five minutes to brainstorm, research, and construct a working model. To compare the use of Design Compass in a group with the use of an individual, three of the participants were placed in a group and instructed to work together on a single model, while the other two participants worked individually on separate models.

Participants were asked to record their steps on the Design Compass as they progressed through the activity. Data in the form of video, screen capture, and Design Compass log files were collected for each of the three groups. Participants were also asked to fill out pre- and post-activity questionnaires.

Results

Results suggest that the Design Compass is well suited for facilitating constructionist activities. A majority of participants reported that the Design Compass is easy to pick up and use, and all five reported that they reflected on their process more than they usually do during a design activity.

In an attempt to assess how closely participants' reporting of steps matched with what they were actually doing, video footage was compared with the Design Compass log files. The footage showed that most of the work during the 'Construction' and 'Test' steps was actually individuals multitasking (such as testing the durability of a material while constructing) or rapidly switching between steps. In the case of the three-person group, individuals within the group were working simultaneously on different steps (see Figure 3).

Figure 3. Group Members Working on Different Steps Simultaneously

The individual on the left is examining and testing out materials, while the individual in the middle is testing the device and the individual on the right is constructing it.

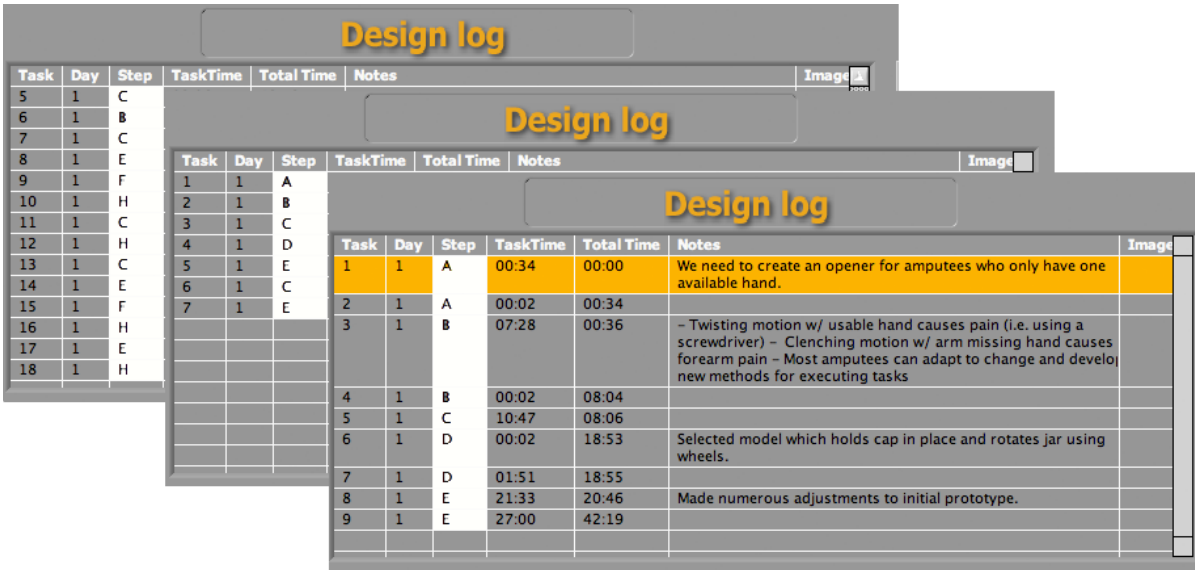

Figure 4. Comparing Log Files Across Groups

A comparison of the three groups to each other reveals that the three-person group worked more iteratively than did the two one-person groups (see Figure 4). Evaluating the order of steps taken by each of the groups shows that the three-person group (far left) completed several iterations throughout the activity, while the two one-person groups (middle, right) worked in a more linear fashion, completing at most two iterations. *Note: A: Define Problem; B: Research; C: Brainstorm; D: Select; E: Construct; F: Test/Evaluate; G: Communicate; H: Redesign*

Discussion

Results from this study suggest that Design Compass can facilitate classroom interactions during engineering design activities through the recording and viewing of quantitative data about steps of the design process. Instructors can use the data to assess students' progress through the design process and determine how to best assist students with future activities. Following the completion of an activity, instructors can facilitate discussion about variance in data between groups.

The Future of Design Compass

The results discussed above are informing the interface and functionality of the next version of the Design Compass currently in development. While including most of the same features and capabilities, the second version will also have the following affordances:

1. Individual and Group Multitasking: Users will be able to select multiple steps to work on at once and designate which group member is working on which step if group members are working simultaneously on different steps.
2. Resources: Instructors will be able to integrate digital resources into the interface, such as images, videos, and text.
3. Customization: Instructors will be able to customize the steps of the design process to align with local standards.

The revised Design Compass interface will be more intuitive for use; an early mock-up is included (see Figure 5).

Figure 5. Early Mock-up of Next Version of Design Compass

This design is intended to be easy for users to pick up and use. Users drag steps into the dashboard arch to begin tracking and adjust the percentages to designate the percent of their time they are currently working on each of the steps. The watch in the top right keeps track of the total time. By clicking on the pencil, users will be able to enter text or draw sketches in the workspace. Behind the workspace are pages for resources uploaded by the instructor and data visualizations of the user's step data. Users can click on the camera to take pictures.

Subsequent versions may include additional features, such as optimization for mobile and touch-screen devices such as the iPad, the ability to compare data across projects, and a physical device

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Greek Salad instead of Spinach or Playful Informatics

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Abstract

Our premises: 1) Logo is especially suitable for developing thinking, 2) Logo's application in primary education is adequately widespread 3) the latest Logo versions are full-fledged programming languages. Based on the premises we claim that Logo can be used in higher education as well for the development of thinking especially in the beginning phase of learning programming in universities. We illustrate the paper with various examples, among others we show how the "round-turn" polar coordinate based curve generating algorithm is generalised from our new round-turn curve generation, which we find even more body syntonic than the original Papert circle. For use in HE, we present a binary tree algorithm and recursive list processing.

Keywords

Logo, higher education, syntonicity

1 Logo and Logo Pedagogy

We think that informatics education is effective only if it is not just useful but enjoyable for the students. If they do not like it, they will not learn it. Based on Papert, we think that algorithms based on syntonicity are easier for the students to understand, thus we also want to follow this idea. Playful Informatics (PI) is fully worked out and proven for primary and secondary education (Farkas, 1993). The introduction of PI to higher education is open for discussion; we plan to implement it in the near future utilising the ideas of fellow teachers.

We think that Logo pedagogy is the most suitable method, often even better than mathematics, for the development of thinking. Turtle geometry is the best tool for applying Polya's methods for problem solving according to (Papert, 1980 p. 30). Turtle geometry makes it possible to develop mathematical thinking not only at an earlier age but also without math phobia in an effective and playful way (Farkas & Kőrösné Mikis, 1989). This method was verified, among others, by the Sakamoto test which showed that results in classes using the Playful Informatics method were significantly better than those achieved in the control group (Farkas, 1999).

In Hungary, Logo is the most widespread software used in primary schools apart from the various Office programs. As well as the general computer technology competitions, Logo school competitions have been organized yearly for many years. Teaching text editing is an aid to learning reading and writing. There is an active debate whether teaching handwriting is still necessary or not. We think that although less and less people write by hand, teaching handwriting is still important for developing manual skills as well as reading skills. We can make the turtle draw the letter forming curves that can be followed by the child's finger, first in bigger, later in lower sizes.

Although text editing is clearly important, the technicalities of other Office programs – with the slogan that what is good for adults will be good for children as well – have arisen many pedagogical problems. Some people think that Logo is a good tool for children to play with but it is no good for anything more. We strongly disagree. Logo is very useful to prepare the learning of programming. Learning programming, which is different from playing with programming tools, is not for child age. While learning programming one meets with concepts that are not evident at a young age, however, to understand them certain methodological elements may be useful that can be effectively demonstrated using Logo. Syntonicity, the ability of empathy, may provide substantial help for drawing a curve and the turtle is a good tool. Building from parts makes one understand structure. Logo is especially fit for handling lists and this is good for problems in logic. Turtle geometry on the screen makes drawing easy and delightful, thereby process oriented and algorithmic thinking gets closer to the user. Logo is also good for developing the Object Oriented Programming paradigm. Its objects can be presented as parts of common thinking, such as turtle shapes, buttons, toolbars, colours, and the attributed properties – names, sizes, base coordinates and behaviour – can be easily understood. Mathematical variables and communication of objects, hiding and inheritance of their properties can be easier to understand if the objects can be linked to images. Based on these psychological and methodological observations and also on the growing size of Logo applications we think playing with Logo is essential in primary and secondary education, while Logo pedagogy is a good tool for teaching programming in higher education as well. In the sequel we demonstrate our ideas by examples.

In the kindergarten, we propose group plays designed for improving algorithmic thinking instead of the actual use of the computer. A good example is the robot game personalised by a turtle. The algorithm is divided into small steps that are performed jointly with the kids. Later a competition can be arranged among the children, each playing a robot. (Kőrösné Mikis & Farkas, 1993)

In the sequel we present some examples in primary education (Section 2), in secondary education (Section 3) and in higher education (Sections 4 and 5).

2. A primary education example: creative ways of circle drawing

Among the turtle geometry examples, such as e. g. superposition and electronic drama plays of turtles for generating mathematical curves (Csink & Farkas, 2008 and 2011), we highlight an algorithm for circle drawing. The idea is based on Papert but in a slightly different and more syntonic way. The original Papert circle algorithm is:

```
repeat 36[fd 1 rt 1]
```

According to Piaget, a child, after looking around, starts to get to know the neighbourhood by feeling around. The circle is the boundary of the area she can reach by touching. We have heard from a 9 year old pupil the algorithm of a circle starting at the origin:

```
repeat 360 [pu fd 55 pd fd 1 pu bk 56 rt 1]
```

We improved this as follows:

```
to circle :r
pu repeat 360 [fd :r pd fd 1 pu bk :r + 1 rt 1]
end
```

With line thickness :v and refining parameter :f

```
to circle1 :r :v :n
pu repeat :n [fd :r pd fd :v pu bk :r + :v rt 360 / :n]
```

```
end
```

This more syntonic circle drawing procedure may help in understanding the concept of radian too. To draw an arc of length one radian let us repeat :r times the drawing of the circle points

```
to radian_arc :r
pu repeat :r [fd :r pd fd1 pu bk :r + 1 rt 1]
end
```

3. Two secondary education examples: syntonic circle drawing and bouncing ball

The following syntonic circle drawing algorithm can be presented in secondary education when learning about polar coordinates. With the origin at one focus, *a* being the half of the longer axis and *e* the eccentricity, the equation of the ellipse is as follows:

$$r = \frac{a(1-e^2)}{1+e\cos\theta}$$

In Logo:

```
make ”r :a * (1 - :e * :e) / (1 + :e * cos heading)
```

Substituting this in to the Logo circle procedure we get

```
pu repeat 360 [make ”r :a * (1 - :e * :e) / (1 + :e * cos heading) fd :r pd fd 1 pu bk
:r + 1 rt 1]
```

Before the above command we need to define :a and :e, for example by

```
make ”a 100
make ”e 0.5
```

Thus our circle algorithm has an epistemological value, namely that it serves as a basis for drawing any curve given in a polar coordinate format. When :r is not a constant as in the case of the circle we only need to give how it varies. So in general our algorithm is

```
to curve :f
;f command list: the radius expressed as a function of the angle
pu repeat 360 [make ”r run :f fd :r pd fd 1 pu bk :r + 1 rt 1]
end
```

Based on the general algorithm:

Circle:	curve [50]
Archimedes spiral:	curve [0.2 * heading]
Sine (100 for scaling):	curve [100 * sin heading]
Cardioid:	curve [50 * (1 – cos heading)]

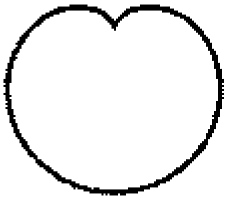

Figure 1. Cardiodid

The question arises whether turtle geometry "prefers" the Cartesian or the polar coordinate system. The child's learning is a self-reflective procedure, she considers herself as the origin. The world gets known by looking around, turning to an object and reaching for it. When a child draws a circle in the sand with a stick, she usually draws it around herself. Therefore, the use of polar coordinates seems to be more natural.

Making games is motivating at any age. We present a bouncing ball in Logo. The ball will be represented by a turtle, thus its direction can be easily seen. The ball-turtle starts in an arbitrary direction and bounces back at the border of a rectangle. As we know, the angle of incidence equals with the angle of reflection. The program is

```
to bounce
if :a > 1500 [stop]
if or xcor > 155 xcor < -155 [seth (-1 * heading)]
if or ycor > 90 ycor < -90 [seth (180 - heading)]
make ”a :a + 1
fd 5 bounce
end
```

The program can be started as follows:

```
make ”a 1 rt random 90 bounce
```

The code can be enhanced in several ways:

- We might slow down the program to be more demonstrative, 1500 steps are too fast,
- Let us draw the frame in which the turtle may move,
- We may put down the pen to make it see how the turtle moves,
- Observe what happens if the turtle reaches a corner; endless loop should be avoided
- We may open gates on the boundary where the turtle can leave
- Start several turtles that can collide and bounce, or alternatively, a new turtle may be born starting at an arbitrary new direction
- The program should give a sound signal at each bouncing
- Slow/speed buttons can be added to the screen
- The reflection angle may be distorted a bit: what happens if it distorts toward the wall?
- Modify the program: write a flipper game
- Introduce a racket on the bottom.

Creative students will have even more ideas and will start into creative developing work. This is the biggest achievement of Logo.

4. A higher education example: a binary tree

Logo is very good for demonstrating recursion, for example drawing a binary tree. The example will be more interesting if the thickness of branches will adapt to the age of the tree. A parameter can be used several times in several ways:

```
to oldtree :a :z
if :z > 0 [
setpensize 2 * :z
fd :a lt 45 oldtree :a / 2 :z – 1 rt 90
oldtree :a / 2 :z – 1 lt 45 bk :a]
end
```

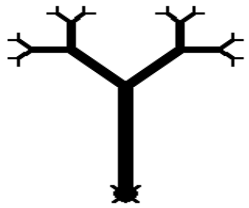

Figure 2. A binary tree drawn with Logo

Before a new branch, the recursion condition can make appear a new turtle that can animate something. Here comes a Comlogo procedure in which each branch is drawn by a new turtle (a flower, a leaf):

```
to blooming.tree :age :trunk_length
if :age = 0 [stop]
fd :trunk_length lt 45
each [maketurtle count all (se pos heading + 90 ”st)]
tell all blooming.tree :age – 1 :trunk_length * 0.7
end
```

Instead of constants, we may use randomness in the above example. Randomness is not easily understood by students, so its effective demonstration is didactically very useful. Let us modify the **tree** procedure. The amount of growth will be random:

```
to real.trees :a :z
if :z > 0 [ fd :a lt 45 real.trees :a / (1 + random 9) :z - 1
rt 90 real.trees :a / (1 + random 9) :z - 1 lt 45 bk :a]
end
```

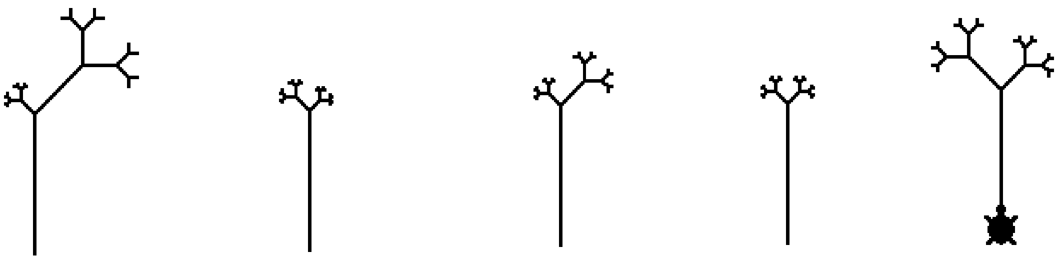

Figure 3. Some random trees: real.trees 100 5

Growth on the left and the right side is 1/ (1 + random 9) times the length of the tree log. Students

might think it over whether this kind of randomness is realistic in the real world.
The growth of trees depend both on random and deterministic factors. For example, they tend to turn towards the sun. Let us assume that if the sunlight comes from the left we multiply with "sun factor" :f the amount of growth to the left:

```
to light_turn.tree :a :z :f
;:f measures how much the tree turns
if :z > 0 [fd :a lt 45 light_turn.tree :f * :a / (1 + random 9) :z - 1 :f
rt 90 light_turn.tree :a / (1 + random 9) :z - 1 :f lt 45 bk :a]
end
```

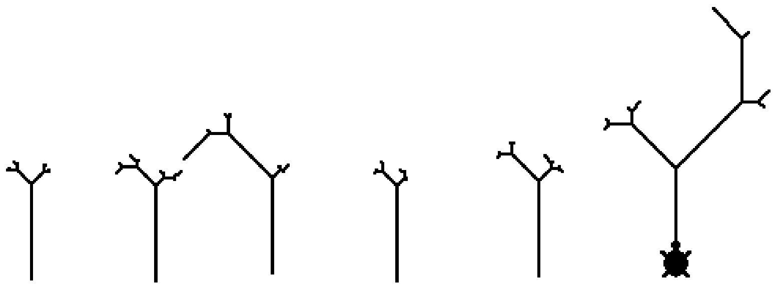

Figure 4. light_turn.tree

In the above setting the tree's turning to the left happens more often, but not always. We can make the example more complex in several ways:

- By introducing brilliance, amount of nutrition etc.
- The state of the trees should be examined yearly
- Make the demonstration of growth video-like
- Write fractal drawing programs

5. A programming theorem with list processing

Our last example demonstrates the strong list processing features of Logo. To demonstrate its strength we present the maximum search programming theorem in Logo.

As a start, let us have just three elements:

```
to max_search_from_3_inputs
make "first readchar
pr :first
make "second readchar
pr :second
make "third readchar
make "max :first
if :second > :max [make "max :second]
if :third > :second [make "max :third]
pr :max
end
```

Generalising:

```
to max_search :n :list
;max search in a list of n items
make "i 1
make "max (item :i :list)
repeat :n - 1 [make "next (item :i + 1 :list)
if :next > :max [make "max :next]
make "i :i + 1]
pr :max
end
```

We can also write it in a recursive way:

```
to max_search_r :n :list
; recursive max search in a list of at least n positive items
if (item :n :list) > :max [make "max item :n :list]
ifelse :n > 1 [max_search_r :n - 1 :list]
[pr :max]
end
```

The code is very compact.

6. Using mother tongue

Not everybody speaks fluent English. We think that using one's mother tongue may be a big help in learning. Lego-primitives can be very useful in this respect. As an example, we exchange *if* for its Greek version:

```
to an
if
end
```

The algorithm is thus easier to understand for a Greek student:

```
to max_search_r :n :list
; recursive max search in a list of at least n positive items
an (item :n :list) > :max [make "max item :n :list]
ifelse :n > 1 [max_search_r:n - 1 :lista]
[pr :max]
end
```

Summary

Logo has been used in education from the kindergarten to the university, as Logo is one of the best tools for thinking development in the Polya style. Logo pedagogy is getting more and more important. The Playful Informatics material and methodology is wide-spread in Hungary. Now we focus our research on the use of Logo in higher education. In this paper we sketch some of our earlier examples and show how the "round-turn" polar coordinate based curve generating algorithm is generalised from our new round-turn curve generation, which we find even more body syntonic than the original Papert circle.

We point out that Logo is very effective for presenting recursive algorithms. Programming theorems, with which the typical introductory programming course starts at the university, can be easily formulate in Logo using list processing techniques. We conclude that Logo pedagogy can be very effective for teaching programming at the basic university level.

A number of well-known and also novel Logo algorithms can be found in (XXX, 2011).

Acknowledgements

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Growing Under Pressure: A Thai School Learning How to Prosper While being Different

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Abstract
This paper describes the evolution over the past decade of the Darunsikkhalai School for Innovative Learning (DSIL) near Bangkok, Thailand. Established as a constructionist school, DSIL aims to be a concrete model for Thailand to better develop its educational system. Daring to be drastically different from conventional schools, DSIL had to endure immense pressure from concerned parents and authorities. In order to sustain, DSIL adopted the principle of organizational learning. This approach allowed DSIL to evolve and carry on while still maintaining its core values. Key aspects of such process are described to show how the school managed to respond to scepticisms regarding curricular content and assessment.

Keywords
School, Learning Organization, Curriculum and Assessment

A School that Nobody Understands

When DSIL was established in 2000, there were less than ten schools in the whole country that were considered “progressive”. Even with that small number, progressive was used conservatively. Therefore, DSIL was something drastically different from what Thailand, and perhaps most anywhere, is used to. At the time, the Suksaphat Foundation, the school’s founding organization, had worked with professor Papert and his team at the Epistemology and Learning Group at MIT for four years trying to seed changes in Thailand’s rigid learning system. Disappointed by the resistance to change (Papert, 1997) and failed collaborations, the foundation decided it needed to create a new learning space from the ground up that can be a Constructionist school from day one.

The Suksaphat Foundation is funded and run primarily by the private sector that came together realizing that the ability to learn is key to the country’s competency in the modern world. Thus, Papert’s vision about “learning how to learn” resonated well and has made Constructionism (Papert & Herel, 1991) the foundation’s main guiding principle. Schools, at least at the time, did not share this same ideology. DSIL’s approach towards learning such as no grade levels, student-driven long-term projects, relatively very little “teaching”, was highly questioned. The initial thirty students belonged to parents who were either business owners or were highly educated—the minority of parents who can foresee the potential benefits of DSIL over the traditional education. Also, many made their final choice based on the good name of the foundation. More than a decade has passed. DSIL now has seventy seven students ranging from primary to high school levels. DSIL is still drastically different from other common schools but the perception is much more positive.

The main focus of this paper is based on the fact that DSIL did not start off knowing exactly what to do. Constructionism was a guiding principle, but translating it into day-to-day actions was extremely challenging. With only four years working with Papert and zero experience in running a real school, DSIL had a great deal to learn as an organization. The greatest challenge was how to keep the school adaptive while not being neutralized by the pressure from the traditional school system.

A School that Learns

DSIL has a culture of accepting change. It uses "learning" as means for a sustainable development of the school. As an official member in the Society for Organizational Learning (SOL), DSIL has adopted a "Learning Organization" model. Founded by Peter Senge from MIT's Center for Organizational Learning, SOL is a not-for-profit organization that focuses on the development of people and their institutions. By being part of SOL, the school was able to adopt useful principles to help govern the organizational learning process. Teachers (or more commonly referred to as "facilitators") participate in daily and weekly meetings to discuss and reflect upon their actions. The discussions are guided by the following Learning Organization Disciplines (Senge et al, 2000).

1. **Personal mastery**: Facilitators set their own goal of how they want to improve themselves. The meetings allow them to reflect on where they are and how to fulfil their goal.

2. **Mental models**: Facilitators are encouraged to be open-minded, ready to accept and learn from each other, and develop trust in each and every member of the organization.

3. **Systems thinking**: Understanding the structure of a system enables more effective planning and problem solving. It enables the facilitators, staff, and students to work together to "see" the causes, develop, and test solutions.

4. **Shared vision**: The vision and strategy of the school is shared and anybody can participate in the development or refinement of such goals.

5. **Team learning**: DSIL has a strong culture of sharing and collaborating. Every member participates in a "show and share" session, which allows teams to emerge to either solve problems or branch off into new directions.

Results

The following are some results that illustrate how DSIL has evolved and sustained itself.

Learning at DSIL

Students at DSIL, especially at the primary level, spend a great deal of their time working on projects that were initiated together between the teachers and students (see Figure 1). The projects are closely monitored and guided by the teachers. The teacher to student ratio is approximately 1:2.5, which has remained the same since the early years (12 teachers and 30 students in 2001 compared to 31 teachers and 77 students in 2011). The idea of reducing the number of teachers often come up especially during financial difficulties, but the school as a whole (school managers, teachers, and others who are involved) decided that it is more important to keep the level of support students receive.

After the initial six years when students at DSIL started secondary school, there were more pressure from parents concerning whether their child could perform well at the national tests. A project based learning approach did not give the level of assurance many parents needed. This concern caused fear that did not exist in the primary level. Every year, a significant number of parents relocated their child to other schools because of this reason.

Driven by this concern, DSIL had to adapt in order to build up trust. The school established a special session to help students master the materials needed for the exams while still spending a significant amount of time working on projects. Figure 1 shows how high school level students allocate a fifth of their time, most of which used to be project time, to study the core subjects needed for the exams. The important point here is that this decision was not made by an individual; it was decided by the school community. Students were part of the discussion and they together decided on what to do. This is an important example of the value of a learning organization. Everybody understood and felt ownership over the decision. We believe that this ownership has made DSIL students perform well (see next section) at the national tests while still spending time on project-based learning.

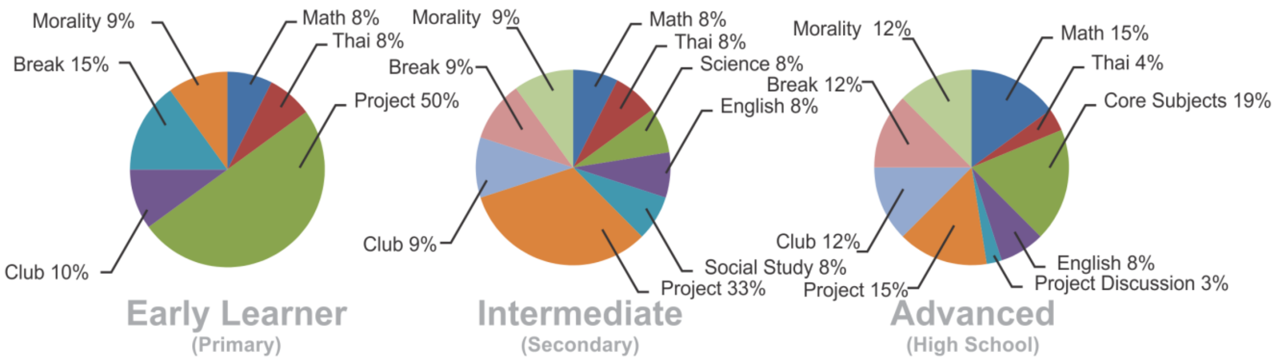
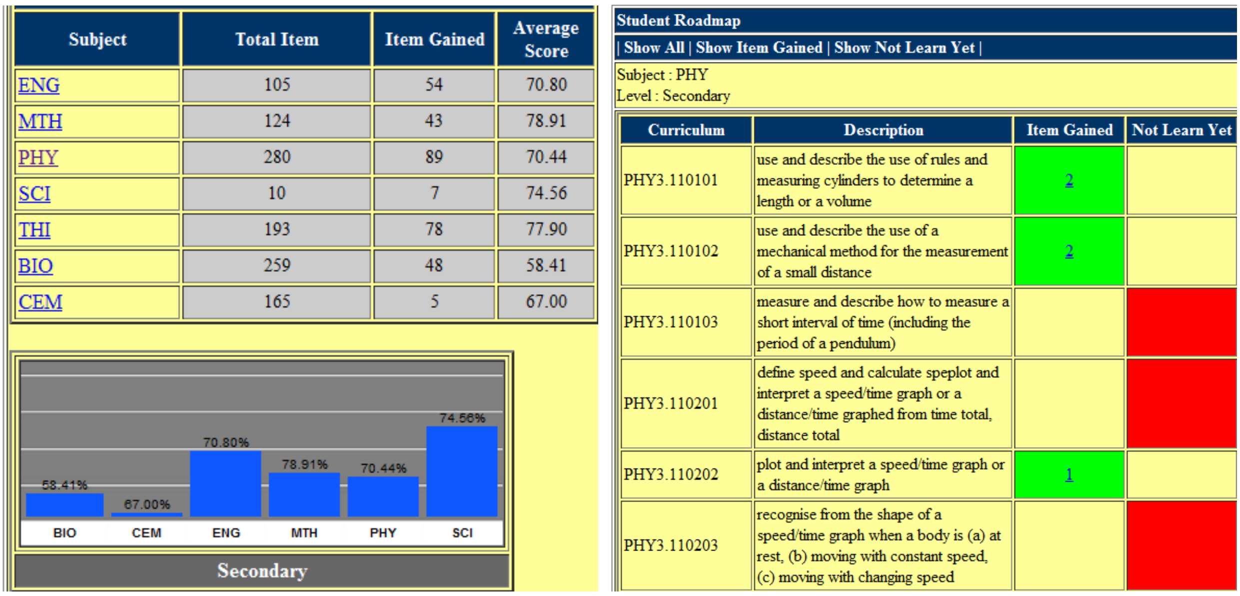


Figure 1. The average time allocated to different activities based on a 40 hours per week period.

Assessment and National Tests

One of the first challenges of DSIL was to figure out how to satisfy the national curriculum while being a project-oriented school. DSIL could lose its school credentials if it cannot cover all the curricular subjects. This issue was managed by adopting a curricular mapping scheme. Every project was dissected and each component mapped to items in the curriculum. The school has developed a tracking system where this information can be entered and tracked on-line by teachers and parents (See figure 2). The system was used in the self-evaluation process by students where they can then discuss the necessity to study or organize projects to cover the missing parts in their portfolio.



Subject	Total Item	Item Gained	Average Score
ENG	105	54	70.80
MTH	124	43	78.91
PHY	280	89	70.44
SCI	10	7	74.56
THI	193	78	77.90
BIO	259	48	58.41
CEM	165	5	67.00

Student Roadmap

| Show All | Show Item Gained | Show Not Learn Yet |

Subject : PHY
Level : Secondary

Curriculum	Description	Item Gained	Not Learn Yet
PHY3.110101	use and describe the use of rules and measuring cylinders to determine a length or a volume	2	
PHY3.110102	use and describe the use of a mechanical method for the measurement of a small distance	2	
PHY3.110103	measure and describe how to measure a short interval of time (including the period of a pendulum)		
PHY3.110201	define speed and calculate speplot and interpret a speed/time graph or a distance/time graphed from time total, distance total		
PHY3.110202	plot and interpret a speed/time graph or a distance/time graph	1	
PHY3.110203	recognise from the shape of a speed/time graph when a body is (a) at rest, (b) moving with constant speed, (c) moving with changing speed		

Figure2. An online tracking system helps teachers, parents, and students to evaluate their progress towards fulfilling the curricular subjects mandated by the Thai school system.

In the recent years, when the first batch of students are nearing their high school graduation, DSIL had to prove to parents that it can do well at the national test. Thailand is known for having one of the world's largest tutoring industries. How can a school perform well if it spends only a fraction of its time on exam preparation? It turns out that DSIL students can manage the exams well. Figure 3 shows that the scores are all above the average. The school ranked 3rd place in the regional district in 2010. Although DSIL values other deeper aspects of learning than that offered in test scores, this outcome demonstrates that a constructionist school can perform well in the traditional system.

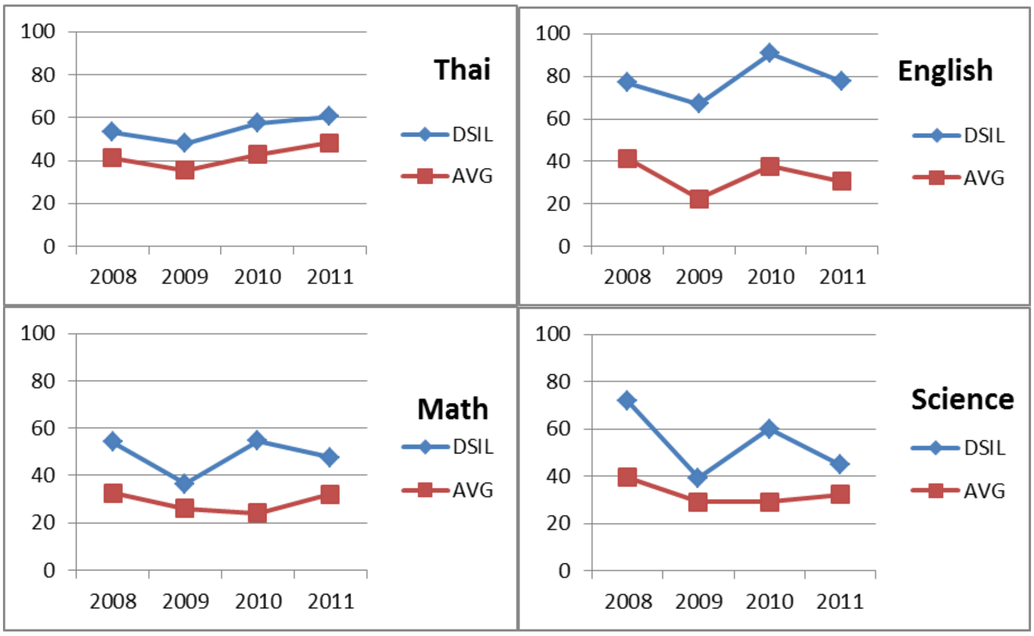


Figure3. Graphs showing how DSIL students have been able to perform well at the national tests.

Public Acceptance

DSIL's twelve year existence is, by itself, a proof that it is not just a short-lived experimental school. DSIL has benefited from the increase in the public's awareness of alternative education driven by the educational act established in 1999. The act shared many values with DSIL and has created a stir in the school system. Although the educational act is arguably a failure in practice, but what goes on in DSIL became more familiar to the general public. Moreover, now that there is some evidence that student can perform well at the national tests, the stress has eased. However, the shift is still not strong enough for most parents. The enrolled students remain children of parents who either own a business or have gone to graduate schools as shown in Table 1.

Year	% Parent owning a business	% Parents with graduate degrees
2001	62.5	35.7
2012	77.3	40.9

Table 1. Parent profile in 2001 compared to 2012 remains similar

Expansion

DSIL remains a drastically different school. There have been five other schools that have adopted parts of DSIL's approach in the past five years but they are not at an organizational level. A rather surprising impact, though, is in the private sector. Through the Suksaphat foundation, many large cooperations such as the Siam Cement Group, Petroleum Authority of Thailand, and Bangkok Bank have become interested in the learning methodologies at DSIL. A number of courses are now being offered to company employees and are popular as means for human resource development. These courses often include DSIL students acting as facilitators. DSIL perceives this interest as an indication that it is developing the right skills needed in today's competitive world.

Conclusions

This paper has described how a constructionist school has been able to grow under immense pressure from parents and the traditional education system. The possibility of parents withdrawing their child has been the greatest threat. Being able to learn and constantly adapt to the situation at hand was key. Through this process, DSIL has proved that it is possible to focus on "learning how to learn", while being able to help students fulfil the expectations of the traditional system.

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Exploring the cone through a half-baked microworld

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Abstract

This paper represents the first part of a didactical proposal that investigates the construction of the geometrical solid of the cone formed each time through the motion of a different geometrical flat shape and thus leading to three different approaches to its properties. This results to having each time a different unit construction-generatrix. Grade 9 pupils after exploring the different types of geometrical solids the half-baked microworld depicts fix it, in order to permanently construct a cone. Pupils work in pairs using a specially designed computational environment that combines multiple representations of geometrical objects and their dynamic manipulation. The environment in which the pupils will work communally is that of constructionism.

Keywords

Cone, angle, slant angle, turn, generatrix, half-baked microworld, constructionism

Introduction

According to Kynigos (2007a) the term half-baked microworld describes a microworld that is explicitly designed to engage its users with changing it as the main aspect of their activity. An opportunity to explore, experiment, test and check conjectures, interpret and form mathematical ideas is offered through the *investigation* of half- baked microworlds. While students are trying to fix their given incomplete program resulting from the removal /modification of one of its items, they discover the mathematics in practice through the experiential activities that the half-baked microworlds constitute.

Difficulties that may arise for the pupils during the investigation of the cone:

1. Are related to the nature of computer programs in general as well as 3-D computer programs. Students during the investigation process tend to use mathematical concepts together with non-mathematical ones, without being fully aware of their existence and meaning (Kynigos, 2006).
2. Stem from the former mathematical knowledge of the students, the cognitive domains where they encounter difficulties in the traditional process of teaching, as well as the overall context of teaching and learning: in the students' cognitive schemas the concept of the angle referred to as a dynamic quantity, i.e. as turn, does not exist due to its static approach in the Greek curriculum.
3. With a combination of the above mentioned: especially the concept of the angle as slope is in itself a source of difficulty for the students, as the one arm of the angle is not apparent. As a result the students have further difficulty in pinpointing its correlation with the distance that the turtle has to cover so as to always form the geometrical solid of the cone.

On the other hand, research shows that when the angle is considered from its dynamic perspective, namely turn, as in MaLT, it helps to deal with common errors like "*students tend to measure the arms of the angle when comparing them*" as it allows pupils to see the angle as turn (Hoyles & Noss, 1987). These are some of the findings that were considered in the design of the half-baked microworld.

Theoretical Framework

The necessity to bring to light methods and tools for a widespread and substantial teaching practice different from the traditional classroom teaching models dominated by the relationship teacher-transmitter quantity of information on the one hand and pupil receiver on the other, are of the most well-grounded in education issues. This dates back to the time of Piaget, about 5 decades ago.

Moreover, Papert (1980) argues when children talk to the computer in a language it comprehends, they may learn more of what they should be learning of mathematics than they can in classrooms without computers. Talking to the computer through programming enables them to think aloud of the way they think and somehow learn to face problems that they pose. The computer enables the child to link his or her experience thoroughly with fundamental mathematical ideas we want children to learn.

Constructionism is a theory which combines constructivism, that gives priority to the individual's active engagement, with the computational tools, that allow us to understand in depth the children's mental processes. Moreover, it is argued that students learn when they are actively engaged in situations that have meaning to them (learning by doing). Pupils learn only when their interest is aroused. And that happens when the situation is such that calls for investigation.

The constructionist theoretical perspective of the present study is based on the assumption that programmable geometrical constructions designed to help children abstract the notion of turtle movement in the 3D space provide a useful environment, due to the didactical engineering that it allows students to do with its representation tools and functionalities, for developing their conceptualizations of geometrical objects, like the cone.

The teaching proposal

The teaching proposal for the construction of the geometric solid cone from 9 grade pupils is developed through three different approaches of its properties, subsequently determining the corresponding structure unit- generatrix: 1. Iterative process of construction of line segments, with a specific slant angle, to the plane of the polygonal base around which they revolve- the construction unit is the segment 2. A set of circles lying on equidistant and parallel planes to the base cone –generatrix, of which the radius decreases in a constant rate until it becomes zero (0) and 3. The rotation of a right -angled triangle (generatrix) around one of its short sides.

Due to space considerations in this paper is presented only the first part, which is expected to last 4 didactical hours. The 14-year-old pupils work in groups of two or three in the computer lab, using a version of Logo developed by *MaLT (MachineLab Turtleworlds)*programming environment. So, the pupils are presented the notation code of the half-baked microworld (see Table 1, left column).

to half_baked :a :b :y repeat 36 [rt(10) fd(:y) gen_1(:a :b :y)] end half_baked (180 -0.3 0.4) to gen_1 :a :b :y bk(:y/2) rt(90) up(:a) fd((36/6.28)*(:y)/cos(:b)) bk((36/6.28)*(:y)/cos(b)) dp(:a) lt(90) fd(:y/2) end	to cone_1 :a :y repeat 36 [rt(10) fd(:y) gen_1(:a :y)] end to gen_1 :a :y bk(:y/2) rt(90) up(:a) fd((36/6.28)*(:y)/cos(:a)) bk((36/6.28)*(:y)/cos(:a)) dp(:a) lt(90) fd(:y/2) end	to cone_2 :a :x :y :n repeat :n [rt(:x) fd(:y) gen_1(:a :y :x)] end to gen_1 :a :y :x bk(:y/2) rt(90) up(:a) fd ((:y*360/:x)/(6.28*(cos(:a)))) bk ((:y*360/:x)/(6.28*(cos(:a)))) dp(:a) lt(90) fd(:y/2) end
Half-Baked notation code	Notation code after Debugging (a version)	Notation code after the extension

Table 1. Notation Codes

The graphical representation of the half- baked microworld that students watch in the 3-D Turtle Scene when they run the procedure is the image of a "sun" lying on the plane.

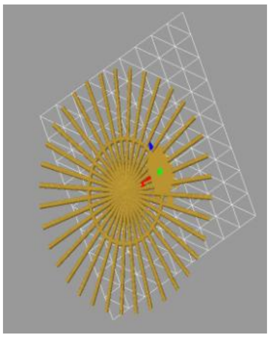

Figure 1. What geometric solids does the turtle construct?

The aim is threefold: 1. to investigate all possible solids that the turtle constructs 2.To tinker with the microworld to construct a cone (see Figure 1) and 3. To present an as much as possible refined the symbolic code, namely allowing the best possible approach of the cone.

In order to achieve the first goal while the basic constructive unit of the solids is hidden, the slant angle, the students have in the beginning to detect it. As a result, in this initial stage, they will have to investigate angular relationships. In this point, the students are expected to find it difficult to distinguish them, since the visual representation of the half-baked code in the Logo Scene in no way resembles to a 3-D geometrical object. As students are engaged in navigating the turtle in MaLT they are expected to gain a sense of the mathematical ideas related to the construction of the different 3-D geometrical shapes (cylinder, truncated cone and bicone) i.e. pinpoint that (:a) is the parameter in the program that determines the shift of the turtle on the screen (slant angle), namely *angular relationships.*

Regarding the second goal: Students while experimenting with the sliders of the parameters (:a), (:b) and (:y) in *Uni-dimensional Variation Tool* (1dVT), that is number-line-like sliders, each corresponding to one of the parameters used in a Logo procedure, will have at first to deconstruct the given construction, with the aim to detect how the parameters function in the composition of the object presented in the Scene. In addition to this, in the given notation code all types of angular relationships are found. These are some difficulties that the pupils have to encounter and are likely not to distinguish their role in the cone construction while tinkering with the half-baked microworld. By means of the "dragging" tool the students also perceive that the figure they have constructed is a "snapshot" of a broader class of figures with some common characteristics. The students eventually, with the combined use of visual and notational representation along with the functionalities of the bi-dimensional variation tool of parameters (:a) and (:b) are expected to be able to ascertain their linear dependence (they end up in relating the length (:b) to the slant angle of the turtle through the mathematical formula :b= :a) (Table 1, column 2 presents a possible version of the code of the cone)

The third goal involves a more "refined" method of tinkering with the half-baked microworld that is the attempt to mathematize further the behavior of the turtle in the construction of the cone. The use of the variation tool *Bi-dimensional Variation Tool (* 2dVT) leads to the expression of further abstraction, according to its structure and use. Intuition dictates that to approximate as best as possible the cone, the number of iterative constructions of its generatrices must increase, namely their *in between distance has to be more dense*. How can they generalize the formula in the notation code, so that the turtle won't turn around a generalized angle theta = :x ? And then what is the number (:n) of generatrices the has turtle has to create, to form always a closed polygonal path so as to approximate as closely as possible the circumference of a circle? Articulating relevant hypotheses conjectures the students will be able to investigate them by means of the bi-dimensional variation tool. The graphical representation of pairs of values of these parameters ensuring that the turtle's motion is always as circular as possible will lead to a hyperbola (Figure 2 depicts the relationship between parameters :x and :n)

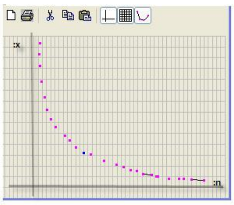

Figure 2. Relationship between (:x) and (:n) parameters

Epilogue

This teaching proposal has not yet been implemented in practice in order to present some pragmatic results. Some of the empirical mathematics related to construction that comes forth through the manipulation of the microworld "half_baked” depending on the chosen course of action is: Students investigate the relationship between the number of degrees of an angle and the length of the generatrix as a necessary condition to create the cone. This concept is the core around which they are invited to create a number of meanings using the symbolic (the programming code), graphical (the visual representation) and the variation tools of the 3D microworld. The students through the investigation of the half-baked microworld, while tinkering with it, manage to transform it into a complete program that permanently constructs a cone, seize the rules behind the process of its construction. The notion of angle as change of direction and plane, the discreteness and the continuity of the number that is indicated implicitly through the alteration of the step of the slider in the 1dVt variation tool, the inverse proportionally quantities, the central angle compared to the length of chord from which the corresponding arc is shown, the investigation of angular relationships are some of the mathematical meanings that the students create while trying to debug and improve the program.

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Design and Learning (D&L) in the Kindergarten

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Abstract

This paper reports about a learning model, "Design and Learning" (D&L), in which mindful interaction with the designed world (the human-mind-made-world), and active involvement in designing objects for this world, serve as an intellectual and practical platform for promoting young children's learning of content, processes, and skills related to the artificial world. The model comprises 7 strands: S1 - the designed/artificial world (products and their use/context); S2 - problem solving (from haphazard to budding systematicity in planning and implementing solutions); S3 - design (from free-form building to reflective construction); S4 - notations (from conventional signs to computer programs); S5 - smart artifacts (from analyzing controlled behaviours to designing adaptive behaviour); S6 - special design for special needs; S7 - the integrative project. Actual implementation examples are presented.

Keywords

Technological thinking, kindergarten, design, artificial world

This paper presents a constructionist learning model, "Design and Learning" (D&L), in which mindful interaction with the designed world (the human-mind-made-world), and active involvement in designing objects for this world, serve as an intellectual and practical platform for promoting young children's learning about contents, processes, and skills related to the artificial world. The rationale of the model is based on the encounter between *Technology* and *Learning*, both taken in their broadest possible sense.

Technology in our rationale has to do with the designed world, the world of artifacts, from the perspective of the *human resources* involved in its creation, e.g., individual and socially accumulated knowledge; beliefs; perceptuo-motor, cognitive and metacognitive processes (Mioduser, 1998). Technology is obviously about tools, artifacts, and the processes and skills related to their design and use. But, more important in our model, it is about *human knowledge*: about its embodiment in an artifact; its generation and implementation for designing a solution; its social construction, accumulation and transmission; its refinement and adaptation when facing new problems. It is also about the way humans *face problems* and *plan* the optimal (not correct) way to close the gap between an existing and a desired state of affairs. It is about the way humans *overcome natural constraints*, modifying nature to satisfy objective or subjectively perceived needs and goals. Finally technology, in a broader view, is about the effect of the recursive interaction between the "inventor's mind" and the "invented world" on the construction of the world as well as on the construction of the mind - and about the effect of this recursive interaction on the phylogeny and ontogeny of human knowledge and perceptions, (Cole & Derry, 2005; Kirlik, 2005; Ortega y Gasset, 1941).

Learning in our rationale relies on the integration of several theoretical approaches: constructivism, social-constructivism and constructionism (Kafai & Resnick, 1996; Papert, 1991; Vygotzky, 1978); situated learning (Collins, Brown, & Newman, 1989); learning-by-design (and its close associates, problem- and project-based learning, Kolodner et al., 2003). Our model locates the learner (individuals and groups) at the centre of the learning process, in the dual role of main engine and main beneficiary of it.

Upon the synergy between *technology* and *learning* we have devised the D&L model. Designing the world has always been a defining characteristic of humankind, affecting both the shaping of the *world* and the shaping of the *world-shaping-mind*. Our leading and simple claim is that *what has been a powerful philological tool supporting the cultural evolution of humankind and human knowledge, i.e., technology, is also a powerful ontological tool supporting the intellectual evolution of learners at all age levels*.

The D&L model and its implementation in the kindergarten

Overall, the D&L model comprises four main layers: (a) learning strands, (b) pedagogical interventions, (c) learning environments and materials, and (d) research activities. A comprehensive description of the model is beyond the scope of this paper and conference presentation, thus, we will focus mainly on the first layer, concerning the learning strands.

In the current implementation of the model in five kindergartens in Israel, contents, skills and processes are organized in seven main strands (S1 to S7) running throughout the year in developmentally-appropriate progression. Strands 1 to 5 are presented in the following sections (not described in this paper are **S6** - 'special design for special needs'; and **S7** - 'the integrative kindergarten project'). In the following sections we introduce each strand, and present examples of learning situations and processes observed in the kindergartens.

S1 - the designed/artificial world (artifacts and their use and context)

In this strand a twofold purpose is pursued, fostering: (a) children's acquaintance with the designed world (it's components, functioning, characteristics), and (b) with human's thinking, knowledge and considerations involved in its design.

At the **content** level, the children deal, in every task, with questions relating to an artifact’s "identity" (e.g., What is it? What is it for? What name should we give it? Does it work "by itself" or do we need to operate it?) as well as its structural and causal configuration (e.g., What parts is it made of? How do the parts work together?). Dealing with these questions is frequently accompanied by classification activities, aiming towards the formation of categories on the basis of structural or functional properties. At the **processes** level the children are actively involved in diverse forms of interaction with artifacts. The artifacts are physically handled, taken apart both manually (analysing causal interrelations) and conceptually (e.g., constructing a simple functional map). Information about artifacts is searched for, and alternative solutions are discussed, and often built.

S2 - Problem solving (from haphazard to budding systematicity in planning and implementing solutions)

While working on this strand's activities, mostly emerging spontaneously in relevant situations of the kindergarten's daily life, a problem solving culture is gradually co-constructed by children and teachers. The trigger for the process is usually a declaration -by a staff member or by one of the children- that "we do have a problem". Iconic signs are used to portray a scheme of the process. After generating and representing (e.g., drawing) several alternative solutions, and discussing their pros and cons, the children cast a vote, selecting the solution they choose to pursue.

Although the situations in which children are involved in problem solving processes relate at first to the artificial realm, very rapidly the approach and use of strategies propagate into other areas of the kindergarten's life (e.g., conflicts among children, dilemmas related to contents being learned), thus becoming a more general tool. In all cases the discussions are supported by the construction of representational charts and graphs of the problem solving process (by themselves artificial/invented constructs).

S3 - Design (from free-form building to design/reflective-construction)

Design is the heart of Technology. As a highly structured or mindful process, as a completely intuitive and unplanned process, or in any combination of these modalities, we design every time we attempt to close a perceived gap between an existing and a desired state-of-affairs by means of an invented solution. Working in this strand, the children get involved in a long journey, which starts with very basic experiences with materials and building kits and intuitive attempts to construct objects and devices. Along the journey, several activities support the construction of a cognitive toolkit for design: reflection on what is being done, verbalization and formalization of procedures, gathering of relevant information (e.g., on materials, procedures, past solutions), using representations and notations for either documentation or planning (linkage to strand 4), addressing moral and ethical questions.

The way the learning proceeds can be depicted as an evolving journey, starting from preliminary acquaintance with materials, tools and processes and the very idea of constructing, via systematic work with building kits and design situations, to the integration of knowledge and abilities in individual, group and whole kindergarten design projects.

Expanding the children's intuitive and creative encounter with the rich repertoire of building kits which normally populate any kindergarten, the children are requested to accomplish various exploration and conceptualization tasks, e.g., composing an ID card for the building parts or blocks, naming them, hypothesizing about their functions; classifying them into meaningful groups; exploring possible assemblages of parts forming functional compounds.

In addition, drawing is used as reflection and thinking aid before, while and after designing and building. First in the progression is drawing-after-building, for the purposes of documentation and communication. In this modality, drawing promotes (and even demands) reflection on the object constructed, e.g., on structural aspects, on mechanisms (e.g., types of transmissions), or representational issues (e.g., scale, 3D to 2D translation, level of detail). Gradually, drawing is introduced for planning purposes, fostering anticipatory thinking, envisioning and concrete representation of the structure and mechanisms required to materialize the object.

S4 - Notations (from conventional signs to computer programs)

Symbolic behaviour is a defining characteristic of humans, and the invention of notational systems one of the essential achievements of the human mind. The generation and manipulation of representations have been part of human's intellectual and cultural development since ever, taking countless forms and fulfilling diverse functional goals. Besides communicative referential tools, external representations are also epistemic tools, “objects to think with”. (Tolchinsky, 2007).

Notational systems constitute a unique strand in our model for two reasons. First, because of its centrality as an intellectual tool serving all layers of technological thinking and making - thoughts get objectified allowing cognitive operations on them, e.g., reflection, analysis, decomposition, comparison, grouping, arguing for or against. By being involved in the construction of notations (e.g., defining conventions, selecting representational units and symbolic entities, establishing representational rules), children deal with both the represented content and the representing means -the 'epistemic tools'- and with the very process of inventing conventional representation and communication systems. In addition, the work within this strand naturally blends with the kindergarten's curricular requirements in the areas of literacy and numeracy.

All activities are built as progressions from concrete involvement in situations in which action and representation are intertwined, via different stages of conventionalization and symbolic translation, to the work on formal representations. One example is the devise of conventions for "telling someone how to navigate a labyrinth". The progression starts as actual navigation in a path, while trying to formalize the description of the required set of actions (e.g., 2 steps forward, right turn, 1 step forward, etc.). Next will be the generation of a description for navigating the labyrinth -and its formal representation- to be communicated to another "traveller". At the end of this progression stand programming activities by which the children construct a program required for a robot to navigate a path (link with strand 5).

S5 - Understanding and constructing artificial-behaviour

Today, controlled systems (e.g., automatic doors, domestic devices, programmable toys, communication and computational devices, robotic systems) have become obvious components of our artificial environment. With the widespread development of microprocessor-based devices, a new category of artifacts infiltrated the traditional and intuitive distinctions between the alive and not-alive, animate and inanimate, human-operated and autonomous: the realm of behaving artifacts. While pertaining to the artificial world, these devices are conceived as endowed with traits such as purposeful functioning capabilities (behaviour), programmability and knowledge accumulation capabilities (learning), autonomous decision-making and adaptive behaviour. The interaction with controlled-artifacts (either as mere user, trouble-shooter, or generator of controlled processes at home or learning settings) demands a new cognitive approach, a different mental modelling of the devices (of their structural, functional and behavioural configurations), and a new set of skills associated with the design and implementation of artifacts' behaviours.

In this strand's activities children are engaged in discussions on the nature of devices "which make decisions" (e.g., an electric kettle or an automatic door), on the physical resources required to construct behaving artifacts (e.g., to be able to move or to sense), and on the logical constructs governing their behaviour (e.g., routines, If…Then… rules). Gradually, they enter the process of constructing a robot's behaviour by means of a specially developed programming interface (Mioduser & Levy, 2010). In the programming activities, the children are engaged in recursive cycles of construction/reflexion, concrete-experimentation/abstract-symbolization, analysis/synthesis, while solving a progression of tasks of increasing complexity.

Concluding remarks

six years of implementation of the D&L model (this year already in five kindergartens) have been enlightening for us as researchers, on a wide range of learning issues emerging from the encounter between children and the artificial world. Examples of significant insights are: perceptions and concepts development concerning the artifacts' world; situated and transferred problem solving; the development of representational and notational abilities; recursive cycles between the concrete and the abstract while constructing (programming) complex artificial behaviours; or the generalization of intellectual constructs consolidated in technological tasks for facing other subjects and even social conflicts and situations. We are currently working on formalizing other components of the model, on devising teacher training materials and procedures, and on expanding the study of the implementation process of the D&L model.

Acknowledgments

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Creating motion models by manipulating parameters that correspond to scientific conventions

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Abstract

The literature in Science Education offers insights on how students' intuitions and everyday experiences interfere with their understandings when they attempt to interpret simulations of scientific phenomena. However, there is no much data about students' strategies when they work with simulations for which there are scientific conventions. Those conventions are likely to be outside the students' everyday experiences and far from common intuitions like the ones about force and velocity. Designing a microworld for simulating phenomena in 3d space, the conventions made are human inventions and don't make a one-to-one mapping to the language the students use in their everyday life. In this Report we describe students' activities as they attempt to create models in a microworld called the "3d Juggler". Two of the main parameters that control the behaviour of the models created in 3d Juggler are "shot azimuth" and "shot altitude".

Keywords

Meaning generation, students' strategies, models and simulations, conventions

Introduction

The Science Education literature offers insights on how students use their intuitions and real life experiences to interpret simulations of scientific phenomena (diSessa, 1993; Sherin, 1996, 2001; diSessa & Sherin, 1998). Designing, however, a microworld for simulating such phenomena, several scientific conventions are made. These conventions are highly possible not to adhere to students' intuitions and everyday experiences, just because they are human inventions, specifically made for the software's purposes.

3d Juggler (Kynigos, 2007) is a microworld (Figure 1) within which the students may create models for simulating motions and collisions in 3d space (Smyrnaiou et al., 2012). Apart from controlling parameters like Sphere Mass, Gravity Pull and Wind Speed, the students may also give their models behaviours that are defined by the "shot azimuth" and the "shot altitude" parameters. Shot azimuth and shot altitude are conventions, as they exist only inside the microworld and just because this is a 3d microworld and motion inside it can be defined in the X, Y and Z direction.

We asked students to create a model within 3d Juggler that would make one of the Juggler's balls hit a specific racket. As they addressed this "challenge", we focused on the strategies they devised for making sense of the "shot azimuth" and the "shot altitude" parameters and the effect these two parameters had on the models they were creating. Our aim was to evaluate our design choice to include in the microworld parameters that correspond to scientific conventions.

The 3d Juggler Microworld

3d "Juggler" is based in a game-like half-baked microworld (Kynigos, 2007). It is designed to offer students opportunities to explore and build models of 3d motions and collisions inside a Newtonian 3d space while playing a juggling game (Figure 1).

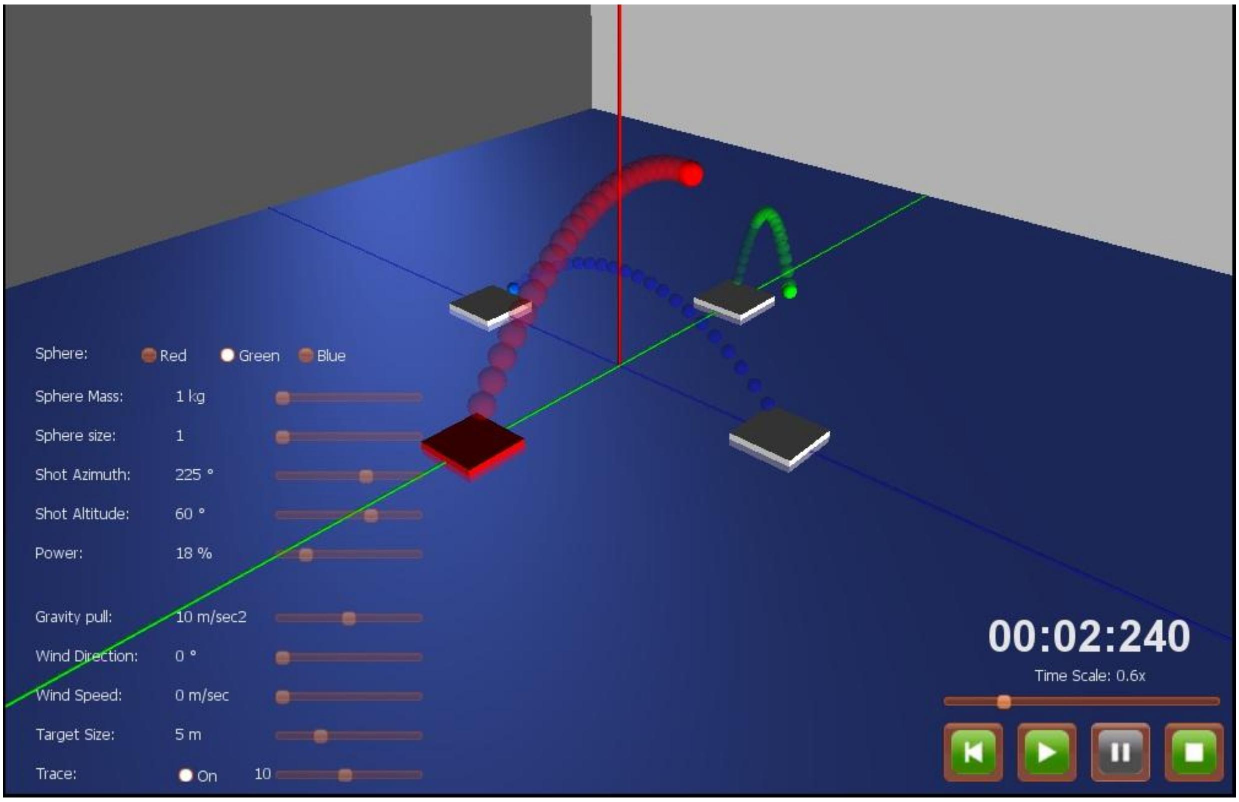

Figure 1: The 3d Juggler microworld

In order to play the game, the students need to first define the initial conditions for running the model that underpins the game. To do so, they have available: a) nine sliders - the sphere mass, the sphere size, the shot azimuth, the shot altitude, the power (corresponds to initial speed), the gravity pull, the wind direction, the wind speed, the target size, b) three balls - red, green, blue, and c) three different camera views for observing the simulation. The students set the values for each of the physical quantities involved by dynamically changing the sliders' values. Once the 3d Juggler game starts, the simulation of the model shows the balls launching in the air according to these initial conditions. If there is no wind (direction and speed), and the gravitational pull is set to 9.81 m/sec2, the balls move in projectile motion trajectories.

Research Design and Context of Implementation

The design-based research method (Cobb et al., 2003) that we employed, entailed the 'engineering' of tools and tasks, as well as the systematic study of the forms of learning that took place within the specific context defined by the means of supporting it.

The study was performed at the 2nd Experimental School of Athens (Ampelokipi) with four 7th grade Secondary School students (2 girls and 2 boys). At this grade, the students haven't been taught at school about motion in 3d space and haven't yet worked with projectile motion.

The three researchers that participated in the session collected data using a screen-capture software (Hyper-cam), a camera and tape-recorders. One of the researchers was occasionally moving the camera to all the Subgroups of students to capture the overall activity and other significant details as they occurred. Background data, like students' worksheets and observational notes were also collected. All audio-recordings were transcribed verbatim.

The students which participated in the Study were divided into two Subgroups. To get familiar with the 3d Juggler Microworld, we initially gave them a warm-up challenge and then proceeded to the main challenge. At the main challenge phase, the students were asked to create a model so as to make "the red ball hit the blue ball's base and stop its motion right there".

In analysing the data, we first looked for instances where meanings generation processes seemed to emerge as the students worked with the 3d Juggler microworld, creating, running and observing models of motions. In addition, we paid attention on how students manipulated the variables that correspond to scientific conventions made for the purposed of the software and used them to create models of motion in 3d space. Specifically, we looked at an excerpt of the students' work with the microworld in which they try to make sense of how the "shot azimuth" and "shot altitude" parameters affect the behaviour of the models they create.

Results

Students' strategies and meaning generation processes

After the introductory activity in which the main point was to get familiar with 3d Juggler, the students -working in Subgroups of two- were given a new "mission" to accomplish. As in 3d Juggler one may control the motion of three different balls starting from three different "bases", the students were asked to make each one of these balls hit another ball's base so as to gain game points. In this process, the students of Subgroup B come to build and experiment with an overall number of 18 different models.

Running and observing their first models, the students seem not to be able to extract any reliable conclusions as for which physical quantities they need to change or for what values to give so as to make their ball hit the racket. This confusion seems to appear as they students manipulate too many variables at the same time and fail to observe the outcome of their actions in the simulation generated. A novice researcher's intervention, leads them towards the direction of manipulating first the "shot azimuth" and "shot altitude" parameter.

The students' attempts to make "the red ball hit the blue ball's base and stop its motion right there", focus around giving specific values those two physical quantities. Still, however, the students' explorations seem not to focus on a systematic process of creating a model, observing and interpreting the outcome and rebuilding it according to the visual feedback.

After a while, they try out giving the exact same value to both shot azimuth and shot altitude. As this doesn't really work, they start giving characteristic values (such as 90°). The student's explorations at this point focus more on giving different values to the shot azimuth and shot altitude parameters and observing the changes in their simulation generated. Being more and more confident after each try out that this is the way to achieve the goal, they come to a first conclusion about the role of the shot azimuth and shot altitude in the represented phenomenon ("the shot altitude is about the height").

In the next models the students create, they seem to move away from characteristic values -like 90 degrees- and try out random values for shot azimuth and shot altitude (206° and 63°). Running models with random values, one of the students describes in detail the simulation generated and explains how the changes they made to the values caused the ball to "move to the left" (phenomenological description).

Since the goal of hitting the racket still hasn't been accomplished, the other student decides to increase the value of the "Power" quantity. "Power" is a parameter that -up to this point- the students have left completely intact. The first student, observing the simulation once again, disagrees with manipulating the "Power" parameter so as to achieve the goal and asserts that "it has nothing to do with the force".

Giving random values for only shot azimuth and shot altitude continues, but now it seems that the students consider that this is not enough, as they haven't managed to accomplish their goal. Having rejected the Power quantity, they try out the effect of the gravitational pull parameter. Reducing the value of the gravitational pull, the students run the model and observe the outcome. The researcher intervenes and reminds the students that "the experiment takes place on the Earth's surface and therefore the gravitational pull is constant and equal to 9.81 m/sec^2". Similarly, when they attempt to change the wind direction and wind speed, the researcher reminds them that the challenge is not affected by "air conditions". Searching for parameters the values of which they haven't changed yet, they decide to also test how the ball's size may help them achieving their goal. Once again, the interpretation they give to the simulation generated leads them to exclude the ball's size quantity from the set of parameters they need to manipulate to make the ball hit the racket.

As the researcher suggests once again that they should try to modify one physical quantity at the time, the students focus on shot azimuth and create several models changing the values for only this parameter. While building these models, the students come across the issue of increasing or decreasing the value of the shot azimuth for hitting the racket with the ball. Observing systematically, model after model, the simulation generated, they come to an understanding on what needs to be done to send the ball on the racket, implement it and explain how increasing the value for the shot azimuth brought the desired outcome.

However, as the ball doesn't stop on the racket, but falls over, one of the students suggests that they need to throw the ball applying less "Force". As the new value for the Force parameter doesn't make the ball go as far as they had predicted, they increase it once more, eventually making the ball reach the racket and stay on it without rolling over.

In this excerpt, coming from the students' interactions with the 3d Juggler microworld, we attempted to identify episodes in which the students come to generate meanings about moving in 3d space. We focus on their strategies when it comes to controlling and manipulating parameters that don't apply to their intuitions and don't use them in their everyday lives to explain scientific phenomena. These strategies are revisited again and again as the students build models to test their ideas, run them to observe the visual outcome and rebuild them according to their understandings. Thus, it seems that those strategies feed meaning generation process as the experience the students gain from working with their models leads them to reconsider and gradually reshape the theories according to the new situations that rise.

Conclusions

The two Subgroups of students, both members of a common Group, are asked to work together so as to make in the 3d Juggler microworld "the red ball hit the blue ball's base and stop its motion right there". Analysing the students' interactions as they work with the 3d Juggler microworld, we focus on their strategies for making sense of the “shot azimuth” and the “shot altitude” parameters and the effect these two parameters have on the models they were creating. In this process we identified strategies such as: “change one physical size at the time and observe its effect”, “give the exact same values to both parameters”, “give characteristic values, such as 90°, the two parameters”, “give random values to the two parameters”, “change the value of a third parameter”, “change/keep constant the gravitational pull on the Earth's surface”, “change/keep constant the wind direction and wind speed”. These strategies seem to feed students’ meaning processes, as the students test their ideas by running the models they create and observing the outcome of their actions and reshape their understandings accordingly.

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The necessity of the tangent

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Abstract

In this paper we present a didactic proposal for a scenario in teaching trigonometric numbers and particularly the tangent, designed for grade 8 students. The scenario is based on the theoretical framework of constructionism. Looking back in the history of mathematics to use those elements that led to the discovery of the concept we want to teach, we create a problem-based learning environment supported by the E-Slate software, from which we use the Turtleworld microworld. Students are engaged in a process where they have to think a way which will allow them to construct scaffolds of different lengths, but with the same slope, which will serve to build all the levels, one by one, of a pyramid.

Keywords

Pyramid, scaffold, ladder, slope, tangent, angle, constructionism

Introduction

Focusing on the constructivist ideas of Piaget and their expansion, due to Papert's theory about constructionism, one can realise the huge change that they bring to instruction and the designing of teaching. Knowledge is structured not only with the individual's experience, but especially with his active involvement in its construction, using experimentation methods, modelling and participatory notification of new cognitive acquisitions. As referred to by Kafai & Resnick, (1996) it is the actual process of learning and teaching that is compatible with constructionism.

In *Mindstorms*, back in 1980, Papert advocated "the construction of educationally powerful computational environments that will provide alternatives to traditional classrooms and traditional instruction." The same time he noted technology of that time was limited regarding its capabilities and ease of use. Since then, considerable work has been done ranging from Logo, Mindstorms, Scratch, ToonTalk etc., that incorporate a constructionist approach to learning (Girvan, C., Tangney, B. and Savage, T., 2010).

Several studies have focused on the implementation of tools as a means of mediation to provide strong visual intuitions supporting production of algebraic meanings and bridging the gap between the act and expression.

The History of Mathematics, on the other hand, provides a significant range of examples with which they can engage students to build from scratch a notion, as when appeared for the first time the necessity of its creation.

With the help of technology not only as a tool but as well as an instrument and a mediator, on one and a historical event related to the use of tangent in Ancient Egypt on the other, the students in this paper will reconstruct the concept of tangent.

Theoretical Framework

As pointed out by E. Ackermann in a bibliographic article on the differences between Piaget's and Papert's theories (2001), Psychologists and pedagogues like Piaget, Papert but also Dewey, Freynet, Freire and others from the open school movement can give us insights into: 1. How to rethink education, 2-imagine new environments, and 3- put new tools, media, and technologies at the service of the growing child. They remind us that learning, especially today, is much less about acquiring information or submitting to other people's ideas or values, than it is about putting one's own words to the world, or finding one's own voice, and exchanging our ideas with others.

Traditional teaching has received numerous criticisms for its results. Contemporary teaching methods nowadays have left aside the immediate information. It is in general accepted that students do not merely take the information provided to them, but translate it according to their own criteria based on their previous knowledge and experience. According to Piaget students have serious grounds not to discard their views thanks to an externally induced anxiety.

Also, the environment, as clearly studied and indicated by Vygotsky, where the concept environment we mean all the characteristics of local culture, such as language, instruments, people, plays its dominant role in shaping the views.

Papert clarifies that constructionism —the N word as opposed to the V word— shares the same views on learning, namely it must be *"building knowledge structures"* and this will be accomplished by progressive internalization of actions. This internalization is achieved by a very cheerful way for the students, when done in a context that allows the conscious engagement with a construction that can obtain public entity. He extends Vygotsky's views in contemporary situations, suggesting as mediation tools the digital media and computers technology.

Our teaching proposal

A few words about the rationale of our proposal

No one is to oppose that planning an activity that motivates-engages students in experiments, computations and assumptions with the aim to highlight a concept or a theorem only positive results can bring, in general.

We estimate, in addition, if such an engagement is based on the origins of the concept we want to teach, then more active participation of the students is achieved. For such scenarios, when used in the teaching of mathematics (as well as in physics), apart from the fact that the students's interest is raised, they also convey, without the need of a modern translation, the ideas and knowledge that gave birth to them, since they can approach them by experimenting, constructing and expressing in their own way.

In terms of putting it in to action, we know that Ancient Egyptians could estimate the slope of a line or a plane. In fact, they used a ratio called skd (pronounced seyket) that corresponds to our current contagent (Bunt, Jones, Bedient, 1981). We use this idea, with the appropriate didactical transformation, to lead the students in a similar situation.

The approach followed in our teaching is that of problem-based learning.

The implementation of the proposal

Our original scenario was designed to be implemented on grade 8 school students in four (4) class hours. The first two hours comprised the concept of the tangent angle as a necessary tool for the indirect calculation of an angle, whereas the following two hours using that ratio to calculate sides of a triangle similar to the original right triangle. Due to space considerations in this paper we will present only the first two class hours. The students work in groups of two or three in the computer lab, using the E-slate software, on worksheets and workbooks.

We briefly present the problem to our students and which substantially raises the following question: "While we have built the first row of blocks of the pyramid and then by means of a scaffold build the second one, where must we place the second scaffold to fill the third row? To what must we pay attention?" This can be an initial discussion on the conditions and the constraints we have in the construction, since the labors-workers will have to work in the same conditions to perform the same, ie maintain the same slope in all the scaffolds (or ladders as depicted on Figure1).
So, we have a figure as the following one, with the corresponding reflection.

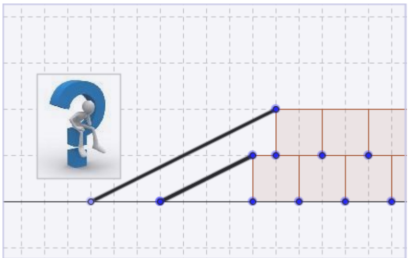

Figure 1. Where should the ladder be placed in order to construct the 3rd row?

Our aim is solely the discovery of the tangent angle. For that, we focus on the first right triangle of figure 1 omitting the remaining elements of the problem and ask students to construct this triangle. We proceed using the microworld Turtleworld of software E-slate where we present a half –baked notation code to the students, which is as follows:

```
to right_triangle :x :y :a
rt 90
fd :x
lt 180-:a
fd sqrt(power :x 2 + power :y 2)
lt 90+:a
rt :y
lt 180
end
```

And we ask to: 1. Interpret the notation code 2. To use the notation code to construct a right triangle of sides 40 and 30 turtle steps with an angle of 30 degrees. 3. Similarly, to construct a right triangle of sides 160 and 120 turtle steps with an angle as the previous one. 4. To activate the sliders of parameters (:x), (:y) and (:a), experiment and construct the two triangles.

We ask our students to interpret the notation code, to assure that all grasp it fully. Otherwise it is possible the subsequent commands that will be asked to create just to play the role of an automation button, slightly different to the ones used in their computer.

It is expected that some students will have difficulty in perceiving mentally and describing the turn of the given angle in the notation code. At this point we will explain to the students the reason why we chose to deal with the given angle. We will need to draw a figure on the blackboard, bring a parallel line from vertex C, to talk about corresponding angles etc, as follows.

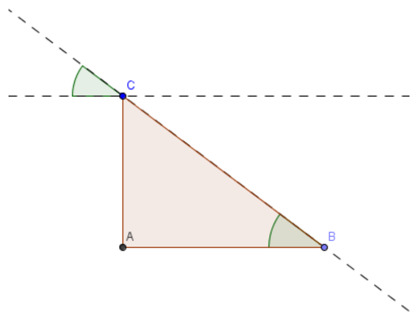

Figure 2. Corresponding angles

We ask from our students to construct two triangles, although they are meant to fail in both, for two reasons. The first triangle is too small and it doesn't provide a satisfactory visual effect, whereas the second one will reveal the weakness of the construction. Also, the sides of this triangle (the numbers corresponding to their length) in combination with the former's sides may give a first suspicion of ratios to the students.

Some groups of students while experimenting with the sliders of parameters (:x) , (:y) and (:a) -if not all- are expected to come up with an angle of 37^o that apparently leads to true results. At this point a software of dynamic geometry would be useful, to easily construct the vertical sides of the triangle and to realize, as much precision though they use, that the angle is not 37^o.

Returning to microworld *Turtleworld* and our initial construction while we ask our students to construct a triangle of sides 40 and 30 turtle steps we explain to them that the software has the ability to calculate the angle precisely, if we give a numeric value as input to the arctan ( ) command. (It would be useful to write that command in another language different to the native language of the students, if there is such a possibility from the program in order to minimize any kind of connotations that can possibly appear). We encourage our students to experiment with the sides of the triangle and the various relationships created between them.

The students will complete this phase by verifying their conjectures for the construction of the second triangle and citing their conclusions in the original problem of the construction of the pyramid.

As an epilogue

This proposal has not been implemented in class, in order to be able to give some results. The idea of the design resulted from the application of the original "historical" problem with dynamic geometry software and the results, cancelled much of our effort to lead the students to an indirect calculation of the angle. That is because the proposed constructions (similar to the ones presented in this paper) were almost all of them the result of simple applications due to the available construction tools.

For that reason when re-designing it we preferred the software *Turtleworld* due to its intrinsic geometry and continuity in design, characteristics "forcing" the students to engage with the problem in a way that leaves no room for escape in other paths.

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Constructionism in the Oilfield

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Abstract

Is it possible to create a constructionist educational program within a large multinational corporation? An example was Schlumberger Excellence in Educational Development (SEED), an international program that included science and technology workshops for students and teachers. The structure and educational approach of these workshops was based on a long tradition of constructionist educational programs, but there were unique aspects to SEED Educational Programs.

The SEED experience provides and "Object to Think With" for other corporations wishing to design an educational program built upon the expertise, organization, and culture of the company.

Keywords

science, technology, workshops, students, teachers, corporations, constructionism, international

Context

SEED was established in 1998 as an educational project within Schlumberger[1], a global oilfield services company. The guiding principle was to build educational programs, activities, and content on the expertise found within the company. Based on this idea, two programs emerged:

- The Connectivity Grant Program[2] provided financing for Internet connectivity and computers to schools in developing countries where Schlumberger was active. This leveraged the computer networking expertise within the company.
- A Science Education Web Site[3] contained content based on the expertise of the many scientists and engineers in the company. The Web site included informational articles and activities on topics related to the science and engineering of the industry, and an Ask the Experts feature[4] where scientists and engineers responded to questions submitted by visitors.

There was a small SEED Core Team, based in Schlumberger's New York City headquarters, which initially consisted of a manager for the Connectivity Grant Program, a web developer and an educator responsible for developing Web site content, and support personnel.

Responsibility for implementing the Connectivity Grant Program, and funding for it, rested with Schlumberger personnel in "The Field" – the locations around the world where gas and oil exploration and production were carried out. The level of support for the program varied greatly from one location to another, depending upon local management enthusiasm.

In 2003 we sought to increase the level of service to the schools in the Connectivity Grant Program by initiating SEED Educational Programs featuring constructionist, theme- and project-based workshops. Technology skills would be learned as needed in the context of projects that the participants would design and build.

Educational Roots

We had a number of good program models to build on: The St. Paul Logo Project[5], the Programa Informática Educativa in Costa Rica[6], and the Logo Summer Institutes[7]. But these projects tended to concentrate on introducing new technologies and then applying them to various content areas. The Workshop Center for Open Education at City College of New York[8] offered a model of a program that focused on content areas and pedagogical approach. It included intensive summer workshops and extensive school-year support.

For SEED we developed workshops around broad themes in science and brought in technologies that were needed to support learning and project development in those areas.

Inspired by Seymour Papert's vision of a learning society[9], we designed the workshops to be intergenerational learning communities with equal numbers of students and teachers. All participants were to be both teachers and learners. Most students were from secondary schools, but there were sometimes primary school students as well. We used the term Collaborative Workshops to emphasize collaboration among participants from several schools[10].

Workshop Design

The first theme was Water[11]. A second theme on Climate Change and Energy was introduced in 2006[12]. Project materials were developed and posted on the SEED Web site to be used in the workshops.

We provided tools and materials for creating virtual and physical models: MicroWorlds[13] and later Scratch[14], wood, plastic tubing and bottles, corrugated cardboard and plastic, and a variety of arts and crafts materials. GoGo Boards[15], along with sensors, motors, pumps and lights enabled the creation of active models. A water quality test kit was included when appropriate.

As participants imagined and designed their projects they often required materials that we had not anticipated. It was not uncommon to take some participants to a local hardware store or electronics street during the workshop to pick up additional materials.

This is an overview of a typical five-day Collaborative Workshop schedule:

<table>
<tr><th>Day 1</th><th>Day 2</th><th>Day 3</th><th>Day 4</th><th>Day 5</th></tr>
<tr><td>Introduce theme</td><td></td><td>Brainstorming</td><td rowspan="3">Project development</td><td rowspan="2">Project development</td></tr>
<tr><td colspan="2">Introduce tools and materials</td><td>Project Planning</td></tr>
<tr><td colspan="2">Gather information and expert input; field trip</td><td>Project development</td><td>Sharing</td></tr>
</table>

The workshop leader would introduce the theme and point to relevant documents that had been placed on the computers, and links to relevant Web sites. Frequently there was a talk by a local expert on a topic related to the theme. Whenever possible there was a field trip. For example, we visited water treatment plants in Mexico City, Cairo and Alexandria, and a water purification and bottling plant in Villahermosa, Mexico. We went to lakes, rivers, and the ocean for water quality testing. In Malaysia we went to a hydroelectric dam and had a tour of the control center that overlooked the turbine room, and visited a university center studying alternative energy sources. We introduced MicroWorlds, Scratch and, the GoGo Board, giving participants enough familiarity with these tools to begin working with them in the context of their projects.

The next stage of the workshop was to design and develop group projects. This process began with brainstorming sessions. Each group of eight to ten people would come up with ideas for what they might do. These were written on large sheets of chart paper and shared with all participants.

Then the groups would narrow down ideas that emerged from the open-ended brainstorming sessions and focus on one or a few projects to develop. Plans were drawn and written on chart paper, shared with the larger group and then posted on the wall for ongoing reference during the development phase of the workshop that followed.

Groups generally divided up tasks according to individual interests and talents. Some built the models. Others programmed the GoGo Board, created a virtual model in MicroWorlds or Scratch, or wrote reports or made PowerPoint presentations. The final afternoon of a Collaborative Workshop was devoted to sharing. Each group reported on their work to the audience, which consisted of all the participants and frequently included visiting dignitaries and Schlumberger managers.

Project examples

Here are some of the projects that were built during Collaborative Workshops:[16]

- Water filtration systems, often based on what had been learned on a trip to a water treatment facility. These often involved passing water through successive layers of sand, cotton, charcoal and other materials[17]. One project, called Agua Viva[18], pumped muddy water into a holding tank where the sediment was allowed to settle. A turbidity sensor made with a light and light sensor was attached to a GoGo Board. When it sensed that the water had cleared, a pump was activated to send the clear water on its way.
- Automatic irrigation systems[19] used a GoGo Board with a moisture sensor buried in the ground to detect when water was needed and then turned a pump on. The pump would turn off when the ground became sufficiently damp.
- Energy-efficient buildings[20] combined traditional and modern means to regulate inside temperature and lighting. A clay tile roof in a wet, rainy climate reduces heat in a house through evaporative cooling. GoGo Boards were programmed to turn fans on and off depending on the values of temperature sensors. Light bulbs would turn off when a light sensor detected daytime and on at night. Solar cells produced electricity to charge batteries or capacitors.
- An energy playground[21] used the motion of a bicycle or merry-go-round to turn a generator and charge a capacitor. At night, as indicated by a light sensor, a GoGo Board controlled relay would switch the capacitor from the generator to a light bulb.
- Solar cookers were popular projects, especially in Malaysia, where a wide variety of designs were built and tested[22].

Growth

The first SEED Collaborative Workshop[23] was held in Villahermosa, Mexico in September 2003, attended by 70 students and teachers. The staff consisted of members of the SEED Core team along with graduate students and faculty from the Future of Learning group at the MIT Media Lab.

As Educational Programs continued in Mexico with two to five workshops each year, it expanded into other countries: Egypt and India in 2004, Malaysia, Russia and Venezuela in 2005, Saudi Arabia in 2006, and China and Brazil in 2007.

Over time the program became more efficient in several ways. As students, teachers and local Schlumberger employees became familiar with the content, tools, and methodology of the workshops, they were able to serve as facilitators. It was no longer necessary to have large numbers of facilitators from the SEED Core Team or the Media Lab at each workshop. We formalized the empowerment of local facilitators by establishing Facilitator Workshops. These were one or two days long, held immediately prior to a Collaborative Workshop, to prepare facilitators to be leaders in the Collaborative Workshops. Some students and teachers participated in workshops over a period of years and became effective workshop leaders. In some cases, notably in Russia, SEED schools hosted workshops attended by participants from other local schools.

The key people in the success of Educational Programs were the SEED Country Coordinators. In some cases this was a part-time position, often shared with a Personnel function, but was most effective when it was full time. Country Coordinators mentored each other. As the program expanded, a newly appointed Coordinator might attend a workshop in a country where the program was established so as to learn the ropes.

International mentorship extended to facilitators as well. When the first Collaborative Workshop was held in Venezuela in 2005, three teachers and a student from Mexico were part of the facilitator team[24].

Lessons Learned

There is anecdotal evidence that SEED Educational Programs had significant impact on participants: A teacher in Mexico initiated a robotics club following the first SEED workshop and has continued it to this day. Former SEED students who are now at university report that their experience in the workshops influenced their academic and career choices in the direction of science and engineering.

The experience with SEED shows that it is possible for a large multinational company to create and maintain an extensive program of constructionist educational activity. The logistics of supporting such a program can be built upon the structure of the company. Educational content can be based on its expertise. But it is also necessary to have professional educators in the program to structure and guide it so as to be educationally sound, and to make the most effective use of corporate expertise.

How can the SEED experience be generalized to other companies? Since each corporation is unique it should not be taken as a prescription, but rather as an “Object to Think With” that can guide the design of a comprehensive educational program. A company wishing to do so should consider these factors:

- What is the expertise of the company? What educational value can be derived from that expertise?
- How is the company structured? How can an educational program be coordinated with, and supported by that organization
- What factors in the company culture can support an educational program? How are education and training done internally? Are there any existing social or educational programs that can be built on? Are there informal grass-roots educational activities conducted by employees that can be consolidated and coordinated into a comprehensive program?

This approach is different from what most companies do as part of their corporate social responsibility programs. Rather than contribute to outside educational programs, SEED was an example of building such a program into the company itself. This is more challenging, but can also be very rewarding for employees and offer unique educational advantages for students and teachers.

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[1] www.slb.com
[2] The Connectivity Grant Program was renamed to be the School Network Program in 2006 See http://www.planetseed.com/location
[3] http://www.planetseed.com/science
[4] http://www.planetseed.com/faq_ask
[5] Kozberg, Geraldine and Tempel, Michael, "The St. Paul Logo Project: An American Experience" in *Logo Philosophy and Implementation*, 1999, LCSI, pp. 22-47, available for download at http://www.microworlds.com/company/philosophy.pdf
[6] Fonseca, Clotilde, "The Computer in Costa Rica: A New Door to Educational and Social Opportunities" in *Logo Philosophy and Implementation*, 1999, LCSI, pp. 2-21, available for download at http://www.microworlds.com/company/philosophy.pdf Also see the Omar Dengo Foundation Web site at http://www.fod.ac.cr/,
[7] Tempel, Michael, *Logo Summer Institutes*, 1993, Logo Foundation, http://el.media.mit.edu/logo-foundation/pubs/papers/institutes.html. Also see http://el.media.mit.edu/logo-foundation/workshops/summer.html
[8] An overview of the Workshop Center for Open Education is at http://www.eric.ed.gov/PDFS/ED120179.pdf. Additional descriptive information and a teacher case study is at http://www.eric.ed.gov/PDFS/ED088862.pdf
[9] Papert, Seymour, *Mindstorms*, 1980, Basic Books, chapter 8
[10] There were also School Workshops – those held in a single school. Some of these were comprehensive week-long events similar to the Collaborative Workshops, but most were a half day or less and focused on a narrow topic.
[11] The Water Project is described at http://www.planetseed.com/science/articles/water-project
[12] The Energy theme was launched in a Collaborative Workshop in Malaysia http://www.planetseed.com/node/22686
[13] www.lcsi.ca
[14] http://scratch.mit.edu
[15] www.gogoboard.org
[16] Reports and documents related to some of the projects were posted on the SEED Web site: http://www.planetseed.com/science/student-science-journal/health-safety. From 2003 to 2005 an online publication program called HDL, developed at the MIT Media Lab, was used to publish project results. The program is no longer active, but the archive of SEED projects is available at http://www.planetseed.com/files/uploadedfiles/voices/workshops/hdl/index.htm.
[17] See examples at http://www.planetseed.com/files/uploadedfiles/voices/workshops/hdl/alexandria/static/html/145.html and http://www.planetseed.com/files/uploadedfiles/voices/workshops/hdl/alexandria/static/html/131.html.
[18] http://www.planetseed.com/node/99116
[19] See http://www.planetseed.com/node/99118 and http://www.planetseed.com/files/uploadedfiles/Science/Student_Science_Journal/project_reports/tanchuk/index.htm for examples.
[20] See http://www.planetseed.com/node/20637 for a description of the Energy-Efficient Building project. Examples are at http://www.planetseed.com/files/uploadedfiles/SMK_Ismail2_SI2Heavan%282%29.pdf and http://www.planetseed.com/files/uploadedfiles/malaysia_smk_binjai%282%29.pdf
[21] http://www.planetseed.com/node/20638
[22] http://www.planetseed.com/node/20644
[23] http://www.planetseed.com/node/22782
[24] http://www.planetseed.com/node/22722

Literamovie – creativity in multilingual and multimedia e-editions of classic texts

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Abstract
This article aims to enrich the conversation about the colonization of students' horizontal discourse by the vertical discourse in school, according the Bernstein's distinction, researching the creative work of students in the context of a project, as a significant factor to this colonization. LiteraMovie Cartoon story© is a hybrid creation combining literature, movie and visualization based on cartoons. The reformation of the classic texts in a post-typography educational environment should be considered as a recreation of the text, based on new, as well as on old literacies. So, during two successive projects in the last two years, students of different grades were led to edit classic texts, creating a multilingual and multimedia e-edition with a cross-cultural perception. Finally, it is proposed that this creativity in producing e-learning objects could be the meeting point of formal and non-formal education, of the claim for knowledge acquired after a planned educational procedure and for learning in-action.

Keywords
Literamovie, hybrid multilingual e-edition, horizontal and vertical discourse, classic texts, creative learning

Introduction

Language teaching in traditional educational systems was mainly book-centred, based on the age-long classic tradition and the large scale typography, using a teacher-centred method as well. Nowadays, a great variety of textual genres are used in language teaching and student-centred methods are adopted, claiming the authentic creation of learning objects. Classic texts are present in contemporary education, although they are supposed to be left back as teaching material of the typography age. In other words, the essential issue of the tension between local and global in contemporary education seems to arouse (Χριστίδης, 2009), as locality is examined under the light of the use of ICTs in education, the new literacies and the globalization.

Furthermore, the review of teaching old-literacy-texts in the post-typography educational environment of new literacies (Reinking et al., 1998) should be neither self-limited to a discussion about the writer's skills or the on-going needs of the reader, nor should new literacies be considered as an external goal that the student has to achieve. For, according to Leu, there is a classified scale of out-of-context skills and knowledge of new, as well as of old literacies (word recognition, knowledge recoding, dictionary skills, understanding, inductive logic, writing procedure, orthography, response to literacy), as a concordance of neutral skills, producing new skills' gateway (Leu et al., 2004). On the contrary, for the New Literacy Studies researchers (Gee, 1990; Street, 1995), reading and writing are considered as formative factors of a conductive social activity through in-context practices, connecting people, language resources, means and strategies and aiming to produce meaning in context. This concept supports the study of the above concordance as a nationally-oriented social practice.

As research focuses on learning methods and practices, it seems to underestimate creativity as a crucial factor in language teaching. In modern post-typography environment, students have the opportunity to deconstruct, reform and recreate texts in a multimodal e-edition using ICTs and to communicate with other communities in order to co-create e-learning objects. This activity may be considered not only as learning by practicing, but also as learning by creating with the claim of a final reading of the text by an educational community and of producing a piece of art and literature to be published.

Textual genres and learning objects

Teaching texts of a specific genre leads to the problem of the strict correlation between the text's structure and the defined opinion (or a sum of opinions) that it proposes about life. Teaching literature sets a different series of issues than teaching sciences, and it sets them differently. As Martha Nussbaum put it, we must take into consideration the genre of the text, as well as to view texts as an extension (or redefinition or refutation) of a genre: novels, for example, in contrast to the complex, as well as formalistic examples by moral philosophers, make the reader participant in and friend of, using punctiliousness, emotional fascination, exciting stories, variety and the uncertainty of good myth-making (Nussbaum, 1990). Additionally, the reformation of a classic text as an e-learning object by an educational community involves students to an alternative learning method, rendering them, apart from learners, co-creators of the learning material. But, should teaching classic literature using ICTs and editing e-learning objects based on it be considered a relative other of the same family or an opposite other? For the more we look into the procedure of the transformation of a classic text in a new communication environment, the more we focus on its deterministic progress to a new genre, obfuscating possible asymmetries between them. Of course, this discussion focuses on the educational use of classic texts, not only on their philological research in general.

The main claim in this correlation is to highlight possible asymmetries between the two, because a presupposition for the activity theory is that the nature of an activity is partly constructed by the tools used in it (Cope & Kalantzis 2004; Engestrom et al. 1999). Two long term projects in teaching language for first-grade-high-school students were planned on this claim: the former, a comparative analysis of the ancient Greek historian Xenophon (Hellenica, 2.1.16-32, The battle in Aigospotamoi) with the ancient Chinese general Sun Tzu's The Art of War, and the latter, The civil war in ancient Corfu by Thucydides: holocaust or Nash's balance (Τζουμέρκας & Πετροπούλου, 2011 [English version in http://en.tzoumerkas.gr/?page_id=26] ; Τζουμέρκας, 2011). Both of them aimed at a Literamovie Cartoon Story production, based on the classic texts with a cross-cultural point of view, as a multilingual and multimedia e-edition (in a tetra lingual e-edition in Ancient and Modern Greek language, English and Latin). A Literamovie e-edition claims not only to represent a text using authentic multimedia, but also to synchronize the multilingual edition of the text in order to facilitate language teaching. This way, when studying a text of the common heritage in a multilingual edition, authenticity, interaction and cultural equity are more feasible. Hybrid e-editions like these set again the issue of the meaning of multimedia in a multilingual environment as an internal factor in the phase of creation, not as an external criterion when assessing the results of the implementation or the suitability of the means used in it.

Hybrid textual genres and Literamovie Cartoon Stories

Additionally, the role of artistic performance in reforming a typewritten text in its meta-typewritten e-edition, not only as pictures on the margins of the text, but as hybrid e-edition should be evaluated. According to Appadurai, the multi-dimensional people flows in the age of the globalization provoke linguistic and cultural *hybridation*, so that hybrid textual genres have risen in contemporary communication field: infotainment, docudrama, dramedy, edutainment etc (Appadurai, 1990). Literamovie Cartoon Stories constitute such a hybrid, constructed using literature and cartoon stories inspired by and transformed in a dramatic performance of the text. According to the principles of the so-called *Learning by Design* the educational community of action must create e-editions, based on the results of the research in the context of a project, with the students in the role of creators and the teacher in the role of the editor. Doing so, students become producers of knowledge in an authentic learning environment, not just users of it.

Both the above projects were planned on three claims: *Exploration activities* with multilingual analysis, synchronization and representation of the text, researching the poetic function of language, as it is expressed by the intonation and the word order in a free-word-order language, like Greek language (see, http://en.tzoumerkas.gr/?page_id=164); *Comprehension activities*, claiming factual analysis of the text, structured in assembling knowledge resources, and especially the construction of a *Hotlist* with an interest for the knowledge resources of the specific case, as for the time, the field and the facts of the battle, the nautical technology in use (triremes, food supplies etc); and finally, the construction of a *Scrapbook* and a *Multimedia Collection* including all the information found and aiming at the *critical understanding of the text*, as well as *a cross literary and cross cultural approach*. But, all these are just materials for the publication of the final version of the text by the students. The third and most important claim was the C*reative activities* requested:

- *Story inside story* – students inspired from the comparative analysis of the texts, wrote an authentic scenario, based on a fictional conversation of the historical persons in future time
- *War diaries* written by students, based on *what if* scenarios, as students played ancient Athenian and Spartan sailors on their way to the battle
- *Authentic music and songs* composed by students, inspired by the historical facts
- *Radio Athenians*, digital radio show in a twelve-hour-show, based on fictional stories of the sailors, narrated by students
- *Authentic cartoons* by students and cartoon stories inspired by the text, and photo stories edited as cartoon stories
- *Authentic choreography* inspired by the text and performed by students
- *Dramatic representation of ancient Greek pottery painting*
- Production and publication of a *tetra lingual and multimedia e-edition* , in ancient and modern Greek language, English, Latin, as an e-learning object

As a Literamovie Cartoon Story includes story timing, designing and creation of authentic pictures and drawings, decoupage and acting, point of view and narration, it is an authentic piece of art. Somebody, though, could raise a plausible objection: is the principle of the uniqueness of a piece of art required in the case of an educational e-edition, as a procedure and as a final product, since it is to be reformed from time to time, and from this point of view it constitutes a continually coming-into-being piece of art? A dramatic historical narration isn't just a narration of unique facts, but also their hermeneutical conception. But, this conception isn't yet an artistic creation. If it is to be poetically reformed, it should be based not only on its uniqueness, as historical narration, but moreover on its claim for 'general truth', as Aristotle put it (1451b:29-33). This is the meeting point of creating and learning.

In the above projects, the final reading of the text and its e-edition has the benefits analyzed by Kalantzis & Cope (2009:56-58). Moreover, this analysis could launch a new tradition in editing classic texts, based on the work of educational communities. Going back to the ancient Greek philosophical controversy about the value of oral and written speech, between Plato and Aristotle, it is the latter that, although Plato was deriding him as *reader*, collecting, scrutinizing and annotating books of his age launched the book-centered tradition, not Gutenberg. Even though the arguments in the modern controversy about the value of new and old literacies reproduce more or less this old discussion, it is the educational communities that will launch a post-typography classic tradition creating multimodal e-editions. Without this activity, the new discussion hasn't got much sense.

Post-typography reformation of a text also refers to its audiovisual and multimodal reconstruction. The necessary skills in the audiovisual and media literacy, as well as in the grammar of the visualization (Kress & Leeuwen, 1996), that students have to improve in order to produce authentic visual materials, are the one issue of this reformation. The other issue is that, as writing skills give an opportunity for creative writing, but they do not demand it, in the same way, the skills in audiovisual and media literacy are one presupposition for planning and materializing authentic e-learning objects, but not the only one. The *authenticity in classroom* (Stevens, 1992:15) is connected with the opportunities offered to students in order to express authentic thoughts and speech, to co-create an authentically reformed digital edition of teaching and learning sources.

Conclusions

The above projects could be a proposal aiming to cure the disability of school to exploit new literacies in classroom, according to the *hypothesis of the disproportion between home and school* (Marsh, 2006). According to Bernstein's distinction between *vertical and horizontal discourse*, they are activities of the former, having a direction towards the future, to the knowledge that is to be acquired at the end of a planned educational procedure. Therefore the discussion about the colonization of children's horizontal discourse by the vertical discourse (Fairclough 2005; Κουτσογιάννης, 2009) could be enriched with this question: which is the role of students' creative work in the context of a project, as a significant factor to the colonization of their horizontal discourse? For colonization, as well as pedagogy of immersion partly underestimate a significant parameter in horizontal discourse, the unasked initiative and inclination of students to be creative. The compliance to a discourse in context, according to *globalization from below* (Fairclough, 2006) may include *creativity in a local context* as well, because real world is something more than a field of adaptation.

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Redefining Constructionist Video Games: Marrying Constructionism and Video Game Design

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Abstract

In this paper we introduce a new class of constructionist learning environments: constructionist video games. These games blend constructionist design principles with video game norms in such a way as to remain faithful to both design traditions. Along with presenting a definition for this type of constructionist environment, we propose two principles for designing constructionist video games that we see as central to creating successful games of this genre.

Keywords

Video Games, Design, Computer-based Constructionist Environments

Introduction

Constructionist learning designs have been successfully used in a variety of content domains, both to motivate learners to deeply explore domain-relevant content and to help learners develop high levels of content understanding. Central to the constructionist design paradigm is the belief that learners should have the opportunity to construct personally meaningful artefacts that can then be publicly shared. Such designs allow learners to set their own agendas and goals thereby becoming architects of their own learning.

Constructionism has a long history of incorporating aspects of video games to achieve desired learning goals. Early LOGO projects utilized game design as an impetus for construction (Papert & Harel, 1991), while other constructionist initiatives used video games to inform the design of the tools learners used when engaging in constructionist activities (Goldstein, Kalas, Noss, & Pratt, 2001; Kahn, 1999).With the increasing popularity of video games in youth culture, some recent constructionist programs have made the building of video games the central task of constructionist learning (Caperton, 2010). Educational researchers have also begun to study the learning that can occur when individuals play video games (Gee, 2003). In the past fifteen years, game studies have explored the possible content children might learn when playing popular commercial video games (Holbert & Wilensky, 2011; Squire & Barab, 2004), the practices gamers develop outside of the game world (Steinkuhler & Duncan, 2008; Stevens, Satwicz, &

McCarthy, 2008), and the ways playing video games might impact common psychology constructs such as visual attention (Green & Bavelier, 2003).

While both lines of work—learning through building games and learning from playing games—have been fruitful, we believe there is an untapped opportunity for uniting the two: designing constructionist video games that make in-game construction the central act of gameplay. This merger is more challenging than it might seem due to a fundamental mismatch between the goal-driven nature of video games and the self-directed exploration advocated by constructionism. Even starting with the best of intentions, it is easy for designers to lose track of constructionist principles in the myriad of design decisions that must be made to create an enjoyable and engaging game. As constructionist designers interested in the educational potential of games, this is a dilemma we must confront: How do we create highly constructionist games that are also consistent with the video game norms players have come to expect? In this paper we propose a definition of constructionist video games and present two key design principles that we believe are central for creating successful constructionist video games: the use of sufficiently expressive construction tools and goal-driven designs that encourage exploration.

Designing Constructionist Games

Juul (2005) defines a game as a "rule-based system with a variable and quantifiable outcome" (p. 36). This widely accepted definition suggests games are constrained by rules and nearly always have a clearly defined notion of success. Furthermore, success in such a game means achieving imposed goals, rather than allowing goals to emerge from play. The definition of constructionist video games that we present here adheres to these aspects of traditional games but also makes the construction of in-game artefacts the central activity of gameplay. Construction activities can take many forms, but it is important that the resulting artefacts are identifiable and useful. By shifting gameplay towards construction (rather than reflex) to achieve in-game goals, the resulting video game has features of both constructionism and traditional video game design.

Few commercial games fit this model of a constructionist video game. Open-ended, exploratory games like *The Sims* have many constructionist aspects, but do not meet the conventional definition of video game due to the lack of 'quantifiable outcomes'. On the other hand, games that have 'authoring modes' like *LittleBigPlanet*, that allow players to construct their own worlds or levels, also do not meet our definition of a constructionist video game as such constructions are not the central gameplay activity. Level creation may in fact be a constructionist activity but it is separate from playing the game itself. In this paper we present two of our own designs, Particles! and RoboBuilder, to serve as examples of constructionist video games as we discuss our two design principles (Figure 1). Particles! (Holbert & Wilensky, 2012) is a platforming video game that encourages players to see physical properties as emerging from atomic-level interactions. In the game, players move through levels by altering the molecular arrangements of blocks, thereby changing their emergent physical properties (bounciness, hardness, etc.), which make up the game world. The second game, RoboBuilder (Weintrop, 2012), is a blocks-based programming game that challenges learners to design and implement strategies to make their on-screen robot defeat a series of progressively more challenging opponents. In both of these games, the construction and revision of player constructed artefacts constitutes the central activity in playing the game. Using these games as "objects-to-think-with" (Papert, 1980), we now move to a discussion of the proposed design principles.

Figure 1. In Particles! (left pane) players rearrange molecules in blocks throughout the game to change the emergent physical properties of objects in the game world. In RoboBuilder (right pane) players construct a robot strategy in a block-based language then watch their robot enact it in competition.

Construction Tools must be sufficiently expressive

Principle 1: Constructionist video games must include sufficiently expressive construction tools so that players can interact with the game in personally meaningful ways.

Papert has written that constructionism was first inspired by frequent walks past an art classroom where students were making soap-sculptures (Papert & Harel, 1991). The "soap-sculpture" approach to mathematics allowed children to take their time to explore ideas of mathematics while building things they actually cared about – things they wanted to show to their parents, their teachers, and to keep for themselves. The soap-sculptures were treasured, not because they were built "correctly," but because they represented the builder's intention. In a constructionist environment, the thing being built must have personal meaning for the builder; the choices made in the construction must be authentic and consequential, and the result should be something one can be proud of. Transferring this important feature of constructionism to video game design is no easy task as video games have predefined goals that are imposed on the player. However, we contend that by providing materials and tools that can be arranged in a wide variety of ways to produce valid constructions, the learner is free to proceed in a way that leads to personally meaningful constructions.

Sufficiently expressive construction tools allow the player freedom to express ideas and strategies that are meaningful in the context of the game while still allowing the player to accomplish in-game tasks. As a game designer, we can adjust the expressiveness of the in-game representations through the breadth of control options provided as well as the granularity of the *building blocks* offered to players. If building blocks are too large, then the game may become too easy, or too restrictive in terms of expressiveness. At the same time, blocks that are too "small" might make the activity tedious or too difficult (Wilensky, 1999). While it is difficult to make a sweeping recommendation as to the size of the components, we believe game designers should err on the side of creativity – construction pieces must be small enough that each construction made by the player is decidedly unique and personal.

RoboBuilder's representational system takes the form of a custom block-based programming language that provides a mix of movement blocks (ex: Forward, Turn Gun Right), event blocks (ex: When I see a Robot, When I Hit a Wall), state blocks (ex: My heading, My Energy), and conventional programming blocks (ex: Repeat, If/Else). Care was taken in the development of RoboBuilder's language to ensure the grain-size of the language primitives were small enough that almost any in-game strategy could be supported while not being so small that complex robot strategies seemed out of reach. Additionally, the number of blocks, the complexity of the task, and the near-infinite number of combinations that could result in a successful robot strategy help give the in-game representational system the expressive power to engage players in the game's central constructionist objective. In RoboBuilder, the choices made by players as they design and build their robot strategies are authentic and consequential as the resulting constructions are the sole mechanism through which the game is played. These decisions are authentic and consequential as they directly impact gameplay and determine the success of the player's robot as it competes. This principle advocates for games to have a highly flexible construction system that allows the builder to create something personally meaningful to accomplish the in-game task.

In-game Goals Should Encourage Exploration

Principle 2: In-game goals and construction tools should encourage exploration and discovery during game play.

In Papert's discussion of microworlds, he stresses the open-ended, exploratory nature of these learning environments. "Although there are constraints on the materials, there are no constraints on the exploration of combinations…the power of the environment is that it is 'discovery rich'" (Papert, 1980, p. 162, quotes in original). The idea of self-directed learning and opportunity to explore through constructed artefacts may seem at odds with the "defined rules and quantifiable outcomes" that we have adopted as a central, defining characteristics of video games. If the game requires specific outcomes how then can we also reward exploration and self-directed discovery?

We believe there are a few ways we can encourage exploration of constructions in a goal-constrained video game. First, by not limiting the player to a single or a small set of winning strategies, the game can reward players for a wide variety of discovered or invented ideas. In this way, the existence of multiple winning strategies supports an epistemological pluralism (Turkle & Papert, 1990); not rewarding one particular solution but instead rewarding any approach that accomplishes the task. This variety of solutions also introduces a qualitative aspect to constructions; players can decide if they prefer one construction over another. Additionally, by creating a low-stakes environment, there is little risk associated with experimentation.

Particles! is designed to explicitly encourage players to explore "molecule" configurations to move successfully through game levels. While the player is given tips throughout the game to introduce him to new types of molecule arrangements (long chains, cross-linking, etc.), the player constructs his own molecular arrangements (instantiated in-game as "bombs") to make the blocks that populate each level. To overcome obstacles the player explores many different molecule configurations until he finds one compatible with his particular play style and accomplishes the challenge at hand. In this way players are encouraged to explore the construction space as they navigate their way through the game. To further support this construction refinement, Particles! allows the player to save each bomb for future use, while limiting the total number of bombs one can carry – in other words, it pays to find a molecular arrangement that can work for many different obstacles.

Conclusion

Both constructionist learning environment and video games have a long history of successfully achieving their design goals through the creation of innovative computational environments. Where constructionist environments have succeeded with respect to achieving desired learning goals by allowing for open-ended exploration and construction, video games have succeed in creating challenging and motivating activities that have permeated kid culture. As designers of constructionist learning environments, we believe there is a potential synergy between these two design traditions. The challenge is integrating the successful aspects of video game design into our learning environments without compromising on the core constructionist principles that help us achieve our desired learning goals. To that end, we have outlined what we view as defining characteristics of constructionist video games and proposed two design principles that we believe will help guide future designers in building successful, compelling constructionist games. As video games continue to grow in popularity in youth culture, we see a great opportunity for constructionist designers to reach larger audiences by introducing Mario to the Turtle.

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"Neighborhoods": Engaging students into inquiring about their local communities from a place-based perspective

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Keywords

Microworld, construction kit, MaSToHF, place-based education, local communities

This poster presentation describes the rationale for constructing a microworld – "Neighborhoods" – aiming to engage students into active exploration of the past, present and future of their local community. It has been designed as a digital tool to situate learning into the students' localities by giving them the opportunity to explore their own perceptions, representations and inquiries about their neighborhoods. Story-telling is coupled with the visualization of events in space and time to allow students to get involved with topics of their local environment which are of personal significance to them and in order to facilitate their historical understanding.

"Neighborhoods" is an open, exploratory learning environment where students can easily explore digital components describing instances of their neighborhood. Based on MaSToHF construction kit (http://etl.ppp.uoa.gr/_content/download/Material/eslate2/mastohf_kit_en_v1_7.zip), this microworld utilizes components such as a timeline, an image map, several descriptors of the city's buildings and other important sources to facilitate exploration and meaning-making processes of their local environment. It connects geocoded data to time and allows students to pose questions related to changes in their localities and historical continuity. The fact of visualizing spatiotemporal information generates a constructionist environment for students to work with and explore the various digital artefacts of the microworld and assist them into subsequently getting involved with real inquiries of their local environment. Students collaboratively explore significant buildings of their area by importing data in a database and by later combining them to provide answers to questions such as "how did our street looked like 20 years ago?" or "when was our school built?". We argue that by setting questions of this kind, students are acquainted with the history of their local communities while they are also enabled to create their own stories or incorporate relevant information into broader socio-historical context. "Neighborhoods" utilizes place-based education principles with the aim to help students develop strong bonds with their community, enhance their appreciation of their local world and turn them into committed active citizens (Smith, 2007).

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Representations of Students' Experience of their Local Environment in their Constructions of Digital Games

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Abstract
The study reported in this poster presents a work-in-progress focusing on unveiling students' representations of their experience of the local environment while interacting with pedagogically designed game microworlds within the context of a place-based educational program.

Keywords
Place-based education, Constructionism, Environmental Education, game microworlds, local environment, representations, city

Rationale and Context of the Study in Brief

Place-based education (PBE) (Gruenewald, 2003; Smith, 2007) is identified as one of the strands of current Environmental Education. By stressing the learners' direct (unmediated) experience of the environment, it almost by definition precludes the use of computer-mediated processes and tools. However, we argue that PBE would have a lot to gain from opening to constructionist frameworks of learning, such as the one we applied in our study. We designed a PBE school program by engaging students 13 to 15 yrs old Greek students first in collaboratively de-constructing a game microworld (PerfectVille) (http://etl.ppp.uoa.gr/_content/download/eslate_kits.htm) and then in collaboratively constructing new game microworlds that would better represent their experience of the city. We aim to explore whether and how meaning generation on concepts and issues related to the students' experience of their city environment is enhanced and shaped through the construction and de-construction of digital artefacts. We focused on studying the students' artefacts and their discursive exchange on concepts and practices related to their local environments, such as their school, neighborhood, or other community places, while they were interacting with the artefacts. The study is a work-in-progress. It is conducted within the context of Metafora, a 3-year EU funded project.

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Knowledge building on line. A new way of training for the primary teachers ?

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In order to overcome the problem of a dispersed rural area, the department of Indre in France has opted for the development of "blended learning" training with collaborative projects on line. The knowledge building on line for primary teachers was the aim. In this experiment which integrates a constructionism model we highlight new ways of learning, knowledge modelling, and training tasks with examples roadmap tasks (Ernst, 2008) created during training. The Moodle plate-form used incorporated virtual worlds and was a space in which the teacher could create and share pedagogical mathematical resources (games for construct the number in Kindergarten, geometry games ...)The evaluation of the experience has been based on both a survey distributed to participants as well as the observations drawn from this experiment regarding the various "learning factors" which are brought together in the pragmatic learning model (Lebrun, 2007). We observe the forum activities where the teachers shared the pedagogical contents and comments. The eight necessary steps for blended learning design (Woodall, 2010) are also taken into account. The author suggests some methodological principles in which the creation and sharing of digital resources have a crucial role. She demonstrates the importance of an experimental approach of collaborative practice, as well as the interest in an implementation of knowledge in clearly contextualised situations for an efficient teacher professionalisation.

Keywords

Constructionism knowledge_building resources training professionalisation blended_learning

Science simulation development with Scratch

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Short Presentation

This study focuses on exploring the use of Scratch for constructing science simulations with students of Senior High School in authentic classroom conditions. We attempt to contribute to the discussion on the main parameters of planning, developing and implementing an effective constructionist approach aimed at engaging students in simulation development as an interdisciplinary project. Building upon earlier researches we implemented alternate teaching strategies as simulation development from scratch and use of preconstructed Scratch projects in order to support student inquiry and learning with models in science. The proposed activities are characterized by a gradual increase in the complexity and difficulty degree and functions as scaffolding during the gradual familiarization of the students with Scratch. In the process, we observed how the students build, test, revise and remix models, collaborate and elaborate concepts developed in previous programming activities, in order to deal with more complex problems. In this study, we report findings of the classroom research aiming at shedding light on 16 year-old students' construction processes as they worked with Scratch. We describe the basic characteristics of the overall process and highlight the differences in the students' levels of engagement and performance. We present students' skills, attitudes and views concerning the use of Scratch for science simulation development and indicate some special features of the programming environment that contribute to or cause difficulty in the creation of an effective learning environment.

The suggested approach was pilot implemented in the framework of the "Project" course in a class of the 1st grade of A΄ Arsakeio General Senior High School in Athens, Greece, during the first four-month period of the school year 2011-2012.

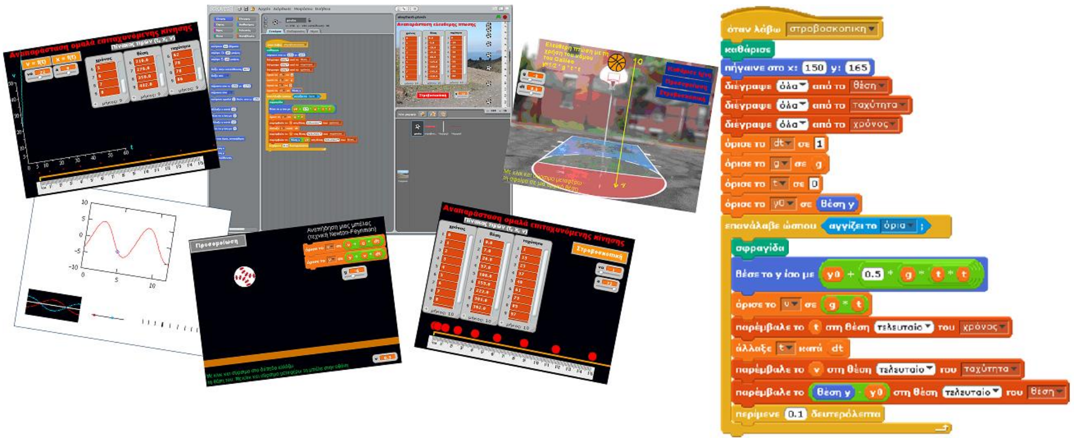

Figure 1. The Scratch environment, sample projects, and sample blocks stack of the students' work.

Keywords

Scratch; constructionism; programming; science simulation

Use of an Exploratory Software for Teaching and Learning about Environmental Issues

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The preliminary study reported in this poster presents an Environmental Education (EE) activity which was designed so that students can use exploratory software to learn about atmospheric pollution in Athens and some interrelated environmental issues (acid rain and urban transportation) and their impact on the Acropolis marbles. The exploratory software is 'E-slate' (http://etl.ppp.uoa.gr and http://e-slate.cti.gr), an authoring tool for the design and construction of microworlds based and run on the basis of specific educational scenarios.

The study took place within four two-hour sessions. Three groups of pupils aged twelve, fourteen and sixteen years old participated in the activity in pairs. Data collection was based on the researchers' observations and notes on the pupils' actions and interactions, the recordings of the pupils' conversations and the pupils' responses to questionnaires.

The findings of the study are presented and discussed. The study concludes that there is particular interest in further exploring the relation between EE and constructionist pedagogy using exploratory software with the aim to enrich both fields and in order to promote more meaningful learning among learners.

Keywords

Environmental Education, Exploratory Software, E-Slate, Atmospheric Pollution, Environmental Issued

Constructivism embedded in the digital activities of the eBooks of Religion for Secondary Education

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Abstract

This paper will present the relationship/links between certain pedagogical principles and modern learning theories which we took into consideration for the design and development of the digitally enriched e-books of Religion for the New Digital School of the Greek Ministry of Education. The theoretical framework of our design decisions is embedded in the human-computer interface elements, the browsing strategies of the e-book, and the "learning strategy" in the interaction of the students with it. In order to understand better how the learning theory of constructivism is embedded into the pedagogy and the design of our digital activities, we shall first present in brief the most important elements of this theory, some of the digital activities we designed and how constructivism is embedded in them. As concerns the teaching principles that are based on constructivism, we took into consideration for the design of digital activities for the enrichment of e-books the development of authentic activity, that is how the student will handle the obtained information in order to transfer the activity into "authentic" (today's real environment). Constructivism aims to provide authentic learning activities related with real world experiences, encourage personal involvement in the learning procedure, the social framework and social interaction promote cognitive constructions.

One of our basic aims for taking into consideration the constructivist model is the change of the view that the content of Religion is isolated from the reality and to show that it deals with human activities that are directly related with daily life, provides experiences in relation to the procedure for the construction of knowledge, provides experiences and appreciates the multiple perspectives, implementation of learning in a authentic context directly related with the real world. E-books include technologies that enhance the cognitive powers of human beings through knowledge construction and thus should be perceived as cognitive tools for educational purposes. E-books facilitate learning due to its innovative features: flexibility in handling information quickly and directly, ability to carry out interactive tasks faster, experiential learning (i.e. learn by doing), provision of learning facilities (e.g. record keeping, automatic scoring, email feedback, information databases, glossaries, transcripts).

Keywords

digitally enriched e-book, religious education, digital applets, digital school.

Collaborative meaning generation processes while interacting with a 3d turtle geometry microworld

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This poster reports on a study conducted to explore the way students collaboratively generate mathematical meanings, as they engage in open-ended, non-standard mathematical problems, that call for planning in advance the course of action to be taken so as to address them. The study took place for 26 school hours in a Lower Secondary Education school, in Athens, with ten 15-year-old students divided in two Groups. The members of each Group -working in subgroups of two-communicated through a web-based Platform called Metafora.

The Metafora Platform hosts three types of tools: Microworlds and Authoring Tools for Microworlds, a Discussion Tool called LASAD and a Planning Tool for describing the course of action to be taken in the process of exploring mathematical concepts when working with the microworlds. The 3d math Authoring Tool is a Turtle Geometry environment that allows the creation and dynamic manipulation of geometrical figures created in 3d space using Logo commands. It is designed to provide students opportunities to express mathematical ideas by integrating the use of symbolic notation (Logo programs) with the dynamic manipulation of 3d geometrical constructions, using specially designed Variation Tools (Kynigos & Psycharis, 2003). For this Study we designed with 3d Math, a half-baked microworld (Kynigos, 2007) called the "Twisted Rectangle". Half-baked microworlds, being incomplete by design, challenge students to deconstruct and reconstruct them, possibly forming new artefacts completely different than the initial ones. In this poster, we will attempt to highlight students' meaning generation processes as they work with the TwR half-baked microworld. We put emphasis, however, on the collaborative shaping of those meanings as students discuss ideas, share parts of their microworlds, negotiate and argue on how to combine those parts while creating new 3d figures.

Acknowledgements

Metafora: "Learning to learn together: A visual language for social orchestration of educational activities". EC - FP7-ICT-2009-5, Technology-enhanced Learning, Project No. 257872.

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Simulator for Learning Robotics Topics in Xbox Consoles

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Abstract

Nowadays, simulation is used as an educational approach to new technologies, letting the learners modify aspects to observe the system's reactions and, as a result, learn through experimentation. The objective of the project presented in this paper is to design and develop a robot simulator using Microsoft specialized software for learning robotics topics and make it easy to download and to operate on Xbox Live platform.

The user will have the option to choose different links of a robotic manipulator from a menu and will be able to join them either through prismatic or revolute joints. Though this activity, the user will be able to construct as many different manipulator configurations, as he can imagine.

Once the user chooses and join the robotic manipulator base and all the links that compose it, he will press a button that allows the system to start explaining the basic methodology for the direct dynamics analysis of robotic manipulators. After that, the system will show the user how his model would move in real life.

Constructionism assures that it is easier to learn science when the learner is committed to the construction of a project. Through this simulator, the user will construct a model that is significant to him and, at the time he constructs a robotic manipulator and sees how it would work in real life, he constructs knowledge as well.

The Xbox console and the Xbox LIVE platform have been chosen for developing this project due to the accessibility of them. Nowadays over twenty million people around more than thirty five countries in the world have access to an Xbox LIVE account. Someone can access to Xbox LIVE even if they do not have an Xbox console. They can do it through a PC, a cell phone with Window operating system, a cell phone with Android operating system and also some devices from Apple company such as iPod, iPhone or iPad. That way, a lot of people all around the world could have access to the simulator.

In this stage of the project developing, the design and programming of the simulator will focus only for usage in Xbox consoles. Nevertheless, it is expected to extend its usage to other electronic devices. Some simulators of robotic manipulator are difficult to be acquired or accessed, first due to their complexity and the basic previous knowledge on issues like software usage or also, robotics. This project pretends to be an accessible learning source for those who want to start acquiring knowledge on robotics field.

Keywords

Constructionism; robot simulator; robotics; Xbox; games console; educational technologies, robotic maipulator.

Mapping Modeling-based Learning in Early Childhood Education

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Abstract

Models are considered integral parts of scientific literacy, reflecting educators' efforts to engage students in authentic Modelling-based Learning (MbL) approaches in science and mathematics. In this context, learning takes place via students' construction of models as analogical representations of physical and mathematical phenomena. The modelling process involves four steps: (a) making systematic observations and/or collecting experiences about the phenomenon under study, (b) constructing a model based on observations and experiences, (c) evaluating the model against, predictive power, and/or explanatory adequacy, and (d) revising the model and applying it in new situations. Despite the consensus in literature about the usefulness of this approach, MbL is not commonly incorporated into educational practice, especially in early ages.

This is a descriptive case study, aiming to develop rich descriptions of young children's engagement in MbL in various contexts in science and mathematics. In doing so, we analysed videotaped conversations and children-constructed models from 7 classes of 4,5-6 year-old children. Each group investigated a topic in science or mathematics for about a month. Teachers collaborated with the authors to develop learning sequences for studying their chosen topics, with the only requirement to use some aspect of MbL in their sequences. Videos were analysed in order to gain better insight in children activity patterns while engaged in MbL.

Findings highlight two different ways that learners can successfully engage in MbL approaches in early childhood education. The first way is essentially using the MbL approach as the means for learning, acquiring experiences and developing conceptual understanding. For instance, one group investigated the functions of the parts of plants, a second group investigated the function of the simple electric circuit, inventing the idea of something (electrons) moving in the circuit as the agent causing the bulb to light. A third group acquired experiences about the properties of the circle through the process of developing representations of carriages, another group developed conceptual understanding of parallel lines through their effort to construct trapeziums and a last group developed representations of the properties of positive and negative numbers through the construction of an elevator. Second, data show that modeling can be also incorporated as a tool for helping children organize and represent the outcomes of a learning process. For instance, one group spent considerable time investigating magnets and their various characteristics, and end up creating a 3-D structure that summarized all those characteristics. A second group after the involvement in a pizza problem found ways to physically represent a circle.Based on these findings in addition to the different means used for the construction of the models (artifacts -3d representations, drawings and physical representations) we will discuss the common ground identified between constructionism, modeling and the Reggio Emilia/project approach.

Keywords: modelling, early childhood education, mathematics, science

Smart Cities Workshop

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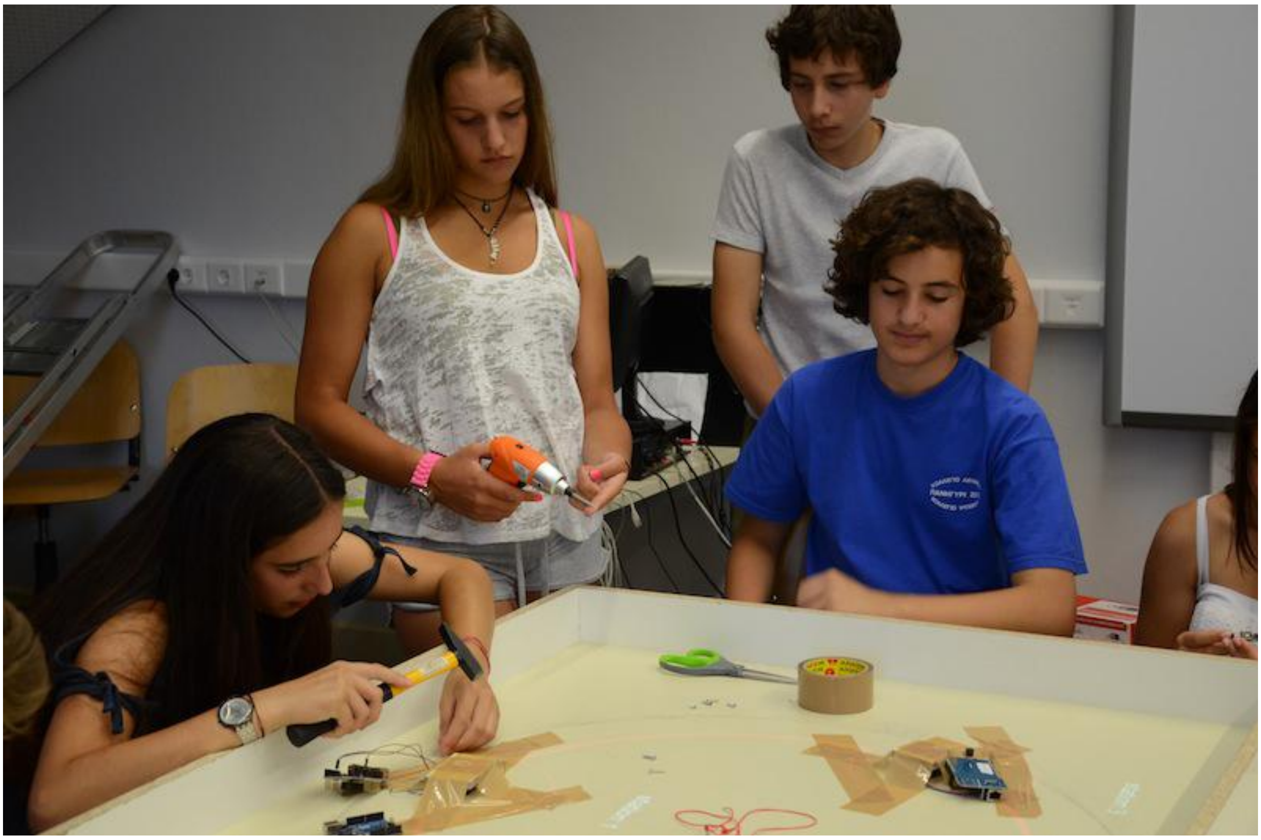
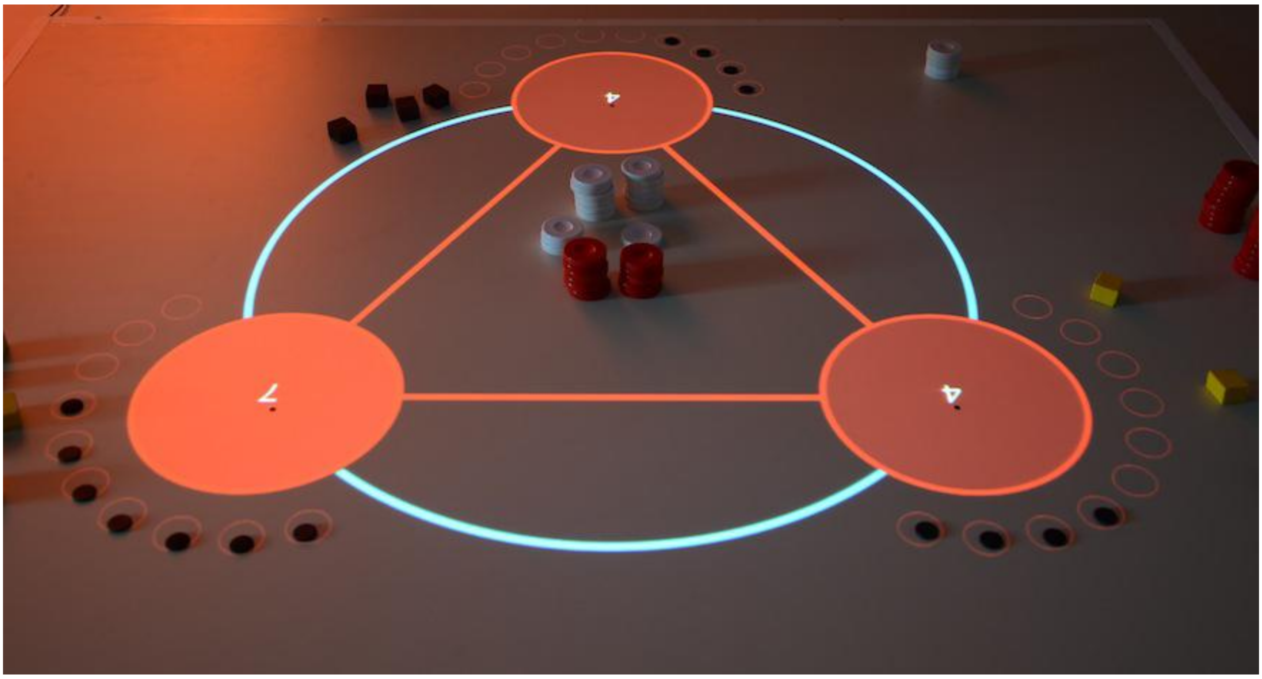
This poster will discuss the design, conduction, results, and conclusion of an experimental workshop for mid-grade high-school students, which introduced the theory, underlying technologies, and operational challenges of Smart Cities and intelligent Mobility on Demand (MOD) systems. MOD systems are transportation networks of parking stations and shared vehicles (bikes, automobiles, etc.) that allow users to make point-to-point trips on demand. In the workshop students brainstormed ideas of how to use sensors, communication networks, incentive mechanisms, and graphical user interfaces to sense inventory imbalances and persuade users to optimally relocate vehicles through price incentives. Furthermore they tested those ideas in practice by designing, prototyping, and playing an interactive board game that implements those technologies and replicates the economic principles of a dynamically priced MOD system.

The students were organized into four teams: the first team developed the electronic infrastructure of the stations from programing three microcontrollers to read data from RFID sensors to having them send messages to a central computer through the Internet, each time a player checked an RFID tag to a station. The second team developed the server program in Java (Processing) in the central computer to collect the incoming messages from the stations, turn them into prices, and visualize them as a color-coded map on the physical surface of the board game through a mounted projector from the ceiling. The third team developed the rules, designed the layout, and helped in the prototyping of the board game that was used to understand perception of payoffs and decision-making of users in the system. Finally, the fourth team developed an agent-based simulation program to explore the impact of user demand patterns on the service rate (performance) of vehicle sharing systems.

Through the synergetic collaboration of the four teams, students learn basic digital electronics, programming, data visualization, computer simulation, game theory, time-management and teambuilding skills by integrating their work on a hands-on collaborative project that stimulates their imagination while emphasizes the results of their efforts. This intensive workshop is designed for graduate level students at the MIT Media Lab and it is the second time it is being offered at secondary level education, with highly satisfactory results.





THE PROGRAM: "EDUCATION FOR ROMA CHILDREN". Description of its actions and perspectives of further development

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The Program focuses on the phenomena of school integration, educational exclusion, school failure, and school drop of Roma children throughout the actions of the Program: "Education for Roma Children". Setting as a later goal the shaping of an education that would lead efficiently and effectively Roma students to social integration, the implemented program has achieved equivalent education of these groups with the native students. Nowadays, more than ever, it is demanded to raise the awareness and sensitivities of the state and of educational and social institutions too, towards their contribution and acceptance of Roma children. The specific project started in 2010 by intervening in schools and benefiting Roma children and indigenous students. By 2013, the basic nine actions of the above program provided assistance to 400 schools with having about 15,000 students benefited.

Total School Units and Students involved in the Program from September 2010 to March 2012

REGION CODE	REGION	PRESCHOOL EDUCATION	PRIMARY EDUCATION	SECONDARY EDUCATION	TOTALS
0	ATTICA	37	51	15	**105**
1	CENTRAL GREECE	14	30	6	**50**
2	SOUTHERN AEGEAN	2	26	0	**28**
3	PELOPONNESE	3	27	0	**30**
4	CRETE	7	8	0	**15**
5	NORTHERN AEGEAN	2	14	0	**16**
6	IONIAN ISLANDS	2	9	1	**12**
7	THESSALY	11	13	9	**33**
8	EPIRUS	1	8	3	**12**
9	WESTERN GREECE	9	37	1	**47**
	TOTALS	**88**	**223**	**35**	**346**

REGION CODE	REGION	PRESCHOOL EDUCATION STUDENTS	PRIMARY SCHOOL EDUCATION STUDENTS	SECONDARY EDUCATION STUDENTS	TOTALS
0	ATTICA	244	2,572	445	**3,261**
1	CENTRAL GREECE	72	565	36	**673**
2	SOUTHERN AEGEAN	5	185	0	**190**
3	PELOPONNESE	15	491	0	**506**
4	CRETE	11	180	0	**191**
5	NORTHERN AEGEAN	2	71	0	**73**
6	IONIAN ISLANDS	9	78	26	**113**
7	THESSALY	354	1,746	236	**2,336**
8	EPIRUS	5	70	13	**88**
9	WESTERN GREECE	89	1,057	1	**1,147**
	TOTALS	**806**	**7,015**	**757**	**8,578**

Mapping Problem-Solving in Early Childhood Education through Problems Involving Construction.

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Abstract

The data presented in this poster was collected as part of a research project aiming to develop a joint mathematics and science literacy curriculum for early childhood education comprising of six common learning axes (experiences, scientific thinking skills, scientific thinking processes, attitudes, conceptual understanding, and epistemological awareness). The curriculum is scientifically justified through data collection and analysis from the implementation of activities, designed by a mixed group of researchers and teachers. In this poster we present data concerning the involvement of children in problem-solving in an effort to map the components of and describe what problem-solving might look like in early childhood education settings.
The data (videotaped incidences, teacher field notes, children's records) was collected from a class of 20 4 year-olds of a Cyprus urban preschool setting, through the children's involvement in a problem-based mathematics learning centre during free play. In this poster we will present the analysis of the data which resulted from the children's attempt to solve two construction problems. The first problem was the Pentomino Problem. The children were asked to find how many different shapes could be constructed with the use of 5 congruent squares, connected along their edges with the use of 5 identical plastic squares. The second problem was the "net of the cube' problem. The children were asked to find different ways to connect 6 squares in order to produce a cube and were given 6 squares from a geometry kit used for building 3D shapes with a very easy clip connection. The children were also given squared paper to record their solutions.
The data analysis allowed us to trace how problem solving can be interconnected with other learning axes (experiences, skills, other processes, attitudes, conceptual understanding, and epistemological awareness) and identify children's strategies. Among the children's strategies we identified examples of mechanistic reasoning (the children after observing constructions which did not allow them to construct a net, tried to explain why these solutions were not correct thus making a hypothesis which led them to correct solutions) and analogical thinking (used analogies in relation to how they had solved other problems in the past). Overall the findings support the point that involvement in construction tasks gives (young) children access to powerful ideas and allows them to exhibit their ability for more sophisticated forms of thinking.

Keywords:

Problem solving, early childhood education, construction problems

Playing Games on-line and at the schoolyard for generating meanings on Science

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Engaging in processes that require working together in groups for addressing complex scientific problems is an issue that has come at the surface lately in the field of Science Education. The Study on which this poster reports concerns how students come to generate meanings about moving in Newtonian spaces as they collaboratively addressed complex scientific situations.

The Study took place in the 1st Experimental High School of Athens with fourteen 13 to14-year-old students divided in three Groups and lasted for 20 school hours. We particularly focus on how students talked about scientific laws and concepts as they observed the motion of different objects while playing games at the schoolyard and as they worked on-line with a 3d microworld called "3d Juggler" (Smyrnaiou et al., 2012). 3d Juggler (Kynigos, 2007) is a game microworld that is designed to offer students opportunities to build and explore models of motions and collisions inside a Newtonian 3d space. The students, after carrying out a set of experiments at the schoolyard using different types of balls (e.g. tennis balls, basket balls etc), moved to 3d Juggler to collaboratively create their own games that would include shooting balls and hitting specific targets. To explain in detail the exact design of their game, the students were also encouraged to use Pixton, a story-telling tool. While working on-line with the 3d Juggler microworld, the members of the Group communicated through a Discussion Tool, which, just like the 3d Juggler Microworld, is integrated in a web-based Platform call METAFORA.

The poster presented during the Constructionism 2012 Conference will include episodes in which the Groups of students discuss around their game constructions and engage in meaning making processes with regard to scientific concepts and laws that underpin the design of their games.

Acknowledgements

Metafora: "Learning to learn together: A visual language for social orchestration of educational activities". EC - FP7-ICT-2009-5, Technology-enhanced Learning, Project No. 257872.

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Using the "D-stage" Kit to develop 2d Science Microworlds

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"D-stage" is designed by ETL as a "kit" for developing 2d Science Microworlds. "D-stage" is a "microworld kit" in the sense that it allows researchers, teachers and students to use it as a template and create a set of 2d Microworlds for simulating phenomena defined by Newtonian or other types of scientific Laws. Designing and constructing new microworlds using the "D-stage" kit, the students have the opportunity to explore the physics laws that underpin the phenomena they wish to simulate and create new and complicated situations to experiment with.

To develop their microworlds the students have at their disposal: a) an area where they may insert objects and observe the simulated phenomena – the "Stage", b) an area where the Properties or Behaviours of the objects appear in the form of sliders (angle, length, mass, radius, delay) – the "Attributes" area, c) an area where the GUI handlers are placed (e.g. the START button) – the "Control" area, d) an area where the values of specific Properties or Behaviours appear in a vector form, e) a Logo Editor for programming the Properties, the Behaviours and the relationships between the objects that appear on the Stage.

When opening the kit, the Stage already hosts only one object programmed to move like a projectile. Making it move in different ways is just a matter of changing the initial conditions through the sliders or changing specific parts of the LOGO Program that underpin its motion. Adding new objects at the Stage is also quite simple for the designer of microworld. The Logo code that controls the behaviour of the already existing object can be copy-pasted and linked to the new object.

In this poster, we will attempt to highlight University students' designing processes as they developed 2d half-baked Microworlds (Kynigos, 2007), using the "D-Stage" kit. We specifically focus on which functionalities of the kit they use and how they connect their design choices with pedagogical and epistemological underpinnings.

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Supporting students' construction of programming mental models with e-books: The case of Computer Science e-book

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Abstract

Teaching programming to lower secondary education students constitutes a very interesting task with particular difficulties in relation to the other subjects in the Curriculum. Students' difficulties in algorithmic thinking and using programming objects for problem solving are well-known and documented in the literature. The key point is that, in computer programming, students need to think about problems, algorithms and data in ways that are quite different from those in regular cognitive activities in the classroom. Constructivist learning approaches determine the prevalent paradigm when teaching computer programming to novices. A series of programming languages and environments have been created for educational purposes. They have been used to support constructionist approaches to students' learning and development in algorithmic thinking and programming skills, e.g. Logo-like languages, programming micro worlds, visualisation programming environments etc.

In addition, e-books are considered as a promising technology for education offering opportunities to extend learning spaces beyond the boarders of traditional classrooms. They are digital format textbooks, enriched with multimedia and digital material, simulations, various resources, interactive applications, learning scenarios etc.

This presentation concerns the Computer Science e-book for Greek lower secondary schools and the affordances offered, for both students and teachers, in introductory programming. The e-book was created in the framework of Digital School programme, a great national and EU funded project implemented by the Computer Technology Institute and Press "Diophantus", under the aegis of the Greek Ministry of Education. Following, indicative examples related to the unit of Algorithmic and Logo programming are given, which can be easily integrated in educational practice to support constructionist learning activities:

Algorithmic: This application is a simple programming environment for the construction of algorithms able to draw simple and complex geometric shapes. It is a Java applet aiming a) to familiarize students and novice programmers with algorithmic thinking and b) to build efficient mental models of the loop structure. The programming engine is implemented using a small set of simple drawing commands in a Cartesian coordinate system (line draw, colour, variable initialisation, calculation and loop commands).

Stepwise programming: This application is an educational game environment helping students to construct the notion of stepwise execution of a program using a small set of commands. The execution space consists of a 10x15 grid of squares which are placed in a way to receive the

structural blocks, following the basic game rules of Tetris.

Drawing with Logo: This application incorporates features that help students to familiarize with a Logo-like programming environment and to develop algorithmic thinking skills. It offers enhanced opportunities for the teachers to design constructivist activities aiming a) to help students in introductory programming lessons and b) to support them to construct effectual representations and mental models regarding programming concepts and notions (e.g. loop command, procedures etc.)

Keywords

Constructionist learning, e-books, programming knowledge, algorithmic, mental models

Acknowledgement

This work has been supported by the Digital School Programme, funded by the European Union (European Social Fund) and the Greek Government, under the NSRF (National Strategic Reference Framework), and implemented by the Computer Technology Institute and Press "Diophantus".

Students' Collective Creativity while Co-Constructing Digital Games on the Idea of Sustainable City

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Abstract

The study reported here presents a work-in-progress focusing on how students' engagement with playing, de-constructing and constructing digital games microworlds on the idea of sustainable city was used as a means for fostering collective creativity.

Keywords

Constructionism, collective creativity, sustainability, sustainable city, digital game design

Rationale and Context of our Study in Brief

Digital game play, design and construction are acknowledged as important contexts for collective creative engagement and production. From the Vygotskian view highlighting children's social play as an important condition for the development of their imagination, to current theorising pointing out digital game literacy as contributing to the enhancement of digital wisdom, creativity is identified, although not explicitly, as an inherent dimension of game play processes. However, it is the constructionist school of thought (Kafai, 1995; Resnick, 2007) that extended the creative potential of children's engagement with digital games from sole game playing to game design and construction. Collaboration among members of a group being involved in playing, designing and creating their own digital games is argued to enhance collective creativity.

Design-based research was used as the method format of the study. The game microworlds that were collaboratively created show a varying degree of imaginative thinking production. Our analysis aims to illustrate how constructionist activity can enhance the students' collective creativity both in terms of acquiring game design skills and on developing a better awareness of the sustainability concept. The study is part of the Metafora project, a 3-year EU-funded project.

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Artificial Intelligence Supporting Collaborative Constructionist Activities in Environmental Education

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Keywords
Artificial Intelligence, Constructionist Activity, Environmental Education

Description

This study addresses the potential of using Artificial Intelligence technology to support educational processes of classroom-based constructionist collaborative activities. Within the context of the Metafora Project a half-baked microworld called Sus-City which was constructed to assist teaching and learning processes within the field of Environmental Education was redesigned to provide real time recorded data on user interaction. The recorded actions are analysed with the aim to provide meaningful information about the progress of the activity as well as to indicate points in which tools could assist the students' learning.   In order to form a concrete idea of how students work and provide a visualization of all recorded actions (loggings) of the users, a special VBA program in MS Excel was implemented and all the data are represented under the same time scale.

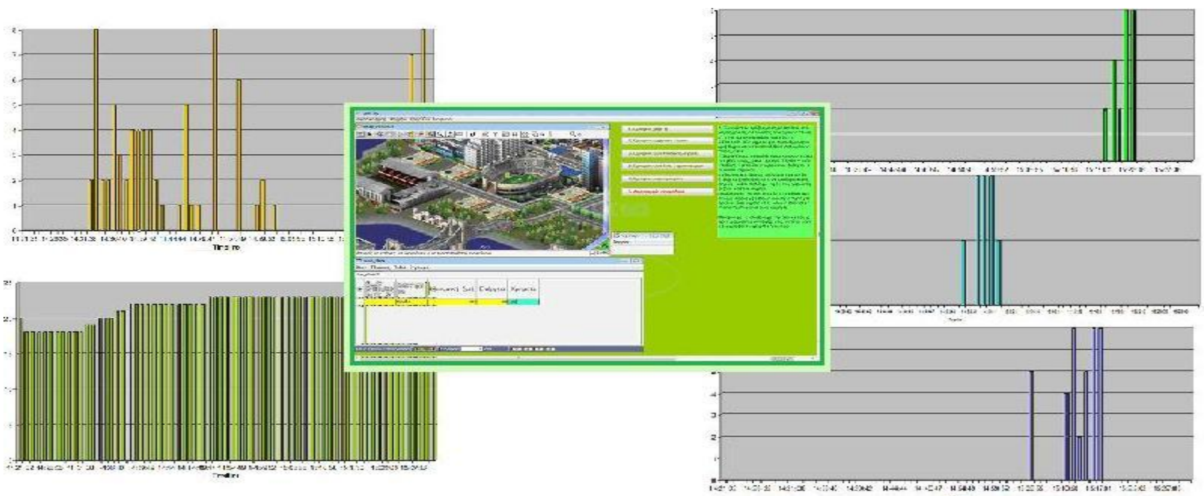

Figure 1 The Microworld and the bar-graphs that represent the user interaction

This preliminary analysis of the collected data seems to confirm the assumption that Artificial Intelligence Technology can provide useful information in a collaborative constructionist activity. We have nevertheless to carefully examine all aspects of the educational process to distinguish where AI assistance is fruitful and more affective for the students and what type of help can provide.

Acknowledgements

Metafora: "Learning to learn together: A visual language for social orchestration of educational activities". EC - FP7-ICT-2009-5, Technology-enhanced Learning, Project No. 257872.

Using MaLT for restructuring the approach of curves in secondary education

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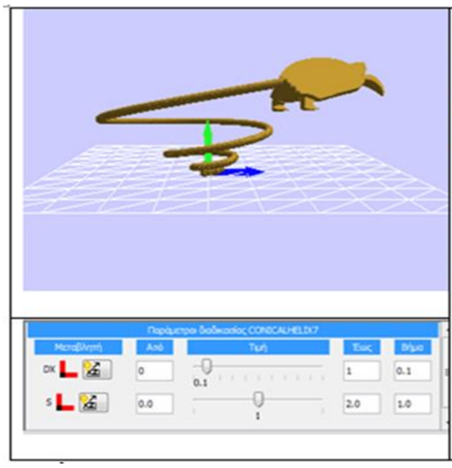
Abstract

In secondary education, at least in Greece, the curriculum involves only the simplest geometric curves and function curves which are abstract representation of mathematical relation rather than geometrical figures (Kynigos and Psycharis, 2003).But, in every kind of practical activity and experience of nature, we constantly encounter curves of widely different forms. What about for arbitrary curves and especially for 3d curves? Yet such investigation is completely natural and necessary. What about notions and activities such as the approximation of the length of a circle for example? What does a straight line mean? What does the shortest path mean?

For a restructuration of this domain (in the sense of Wilensky, 2010) we used MaLT, a 3d Logo / Turtle Geometry environment (http://etl.ppp.uoa.gr) to design a microworld for a differential approximation of curves (Fig. right). The turtle movements reflect exactly the way a curve is designed in space and give to even young students the ability to study, explore and symbolically express these movements by means of logo programming language, at least at an intuitive level, before they reach the complicated formulas of differential geometry.



```
to conicalhelix :dx :s
if [:s>65] [stop]
lr(40*log((:s+:dx)/:s))
lt(400*log((:s+:dx)/:s))
fd(:dx)
conicalhelix(:dx :s+:dx)
end
```

```
to conicalhelix :dx :s
if [:s>65] [stop]
lr((40/:s)*:dx)
lt((400/:s)*:dx)    fd(:dx)
conicalhelix(:dx   :s+:dx)
end
```

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Using a social bookmarking system to enhance the environmental and geographical learning of secondary students. A pre-study review

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Abstract

The research study focuses on the investigation of new practices and teaching strategies for developing geographical and environmental conceptions, based on socio-cultural constructivism and the active - collaborative learning. The constructivistic view of learning environmental concepts, combined with the use of social bookmarking system (SBS), has as a result the students' integration into a dynamic study, relative to their life and future (Exarchou & Klonari, 2011).

Keywords

Environmental and geographical learning, socio-cultural constructivism, SBS

Research Central questions, Method and Expected results

The research questions are: How can SBS be used to enhance the environmental learning of secondary students? How can SBS be used by secondary students to better understand the environmental issues that affect their lives? What role does socio-cultural constructivism play in learning experiences that employ SBS? How can students interact among themselves and with the SBS, based on socio-cultural constructivist principles? What are the students' conceptions of the effectiveness of SBS to enhance their environmental learning? The method is Transdisciplinary Case Study (TdCS) with ethnographic and action research approaches (Stauffacher, 2010) and the study is estimated that a) it will help students to "learn how to learn", constructing new ideas and using the pre- existing experience and knowledge, b) it will stimulate students' interest in learning of environmental issues (Klonari et al., 2011) and c) it will encourage students -using SBS- to investigate, to share their arguments and to be in quest of solutions to other environmental and social issues, which influence different areas of human activity (Klopfer et al., 2009).

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3D in Excel

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Abstract

A method is presented of explaining the principles of 3D graphics through making revolvable and sizable projections of cube in Excel with solved problem of overlapping of the faces.

Keywords

Excel, 3D graphics, projection, overlapping

Introduction

Virtual reality applies to environments that simulate physical presence in the real or imaginary worlds. 3D computer graphics constitutes the basics. The technology is used in computer games, films, education software, etc. Traditionally, virtual reality environments are developed by using programming. However, the equations that govern the transformation from 3D to 2D are easy to evaluate in spreadsheets. Creating a projection of a 3D figure in Excel is an interesting introduction to 3D graphics without any need for programming. In the workshop, a method is presented of explaining the principles of 3D graphics through making revolvable and sizable projection of cube in Excel with solved problem of overlapping of the faces. Orthographic parallel projection is used. In a constructivist way, students comprehend the principle of depicting 3D objects on the computer screen when creating the applications. A 90 min lesson comprising Sections 2 and 3 of this paper was taught nine times to 147 students of teaching informatics and applied informatics. All participants found the lesson interesting. Out of the 45 who had not understood the principle of 3D graphics before the lesson, 44 comprehended it in the lesson.

Orthographic parallel projection

Let $Oxyz$ be orthonormal right-handed coordinate system (Fig. 1). Let plane ρ be in distance 1 from point *O*. Let line *p* be going through point *O* perpendicularly to plane ρ. Let point O' be the intersection of line *p* and plane ρ. Then, O' is the orthographic parallel projection of point *O* onto plane ρ. Plane ρ is the projection plane, vector $\mathbf{OO'}$ is the projection vector; its length is 1. Angles ϕ and θ give the position of plane ρ through vector $\mathbf{OO'}$. They go from $-180°$ to $180°$ and from $-90°$ to $90°$. If $\theta = 0$ and $\phi = 0$, then vector $\mathbf{OO'}$ merges with axis x and plane ρ is parallel to coordinate plane yz. Then, let x', y' be the intersection lines of plane ρ and planes xy, xz. If x', y' are scaled by the unit of axes *x*, *y*, starting at point O', then coordinate system $O'x'y'$ is defined in plane ρ. Let $A(x, y, z)$ be point in space. Let line *r* be perpendicular to ρ, that is, parallel to $\mathbf{OO'}$, and going through point *A*. Intersection $A'(x', y')$ of line *r* and plane ρ is the orthographic parallel projection of point *A* onto ρ. It holds that (Benacka, 2008)

$$x' = -x \sin\phi + y \cos\phi, \tag{1}$$

$$y' = -x \sin\theta \cos\phi - y \sin\theta \sin\phi + z \cos\theta. \tag{2}$$

If we identify plane ρ with the computer screen, then we can project any 3D figure on it provided we know the *x*, *y*, *z* coordinates of the vertices.

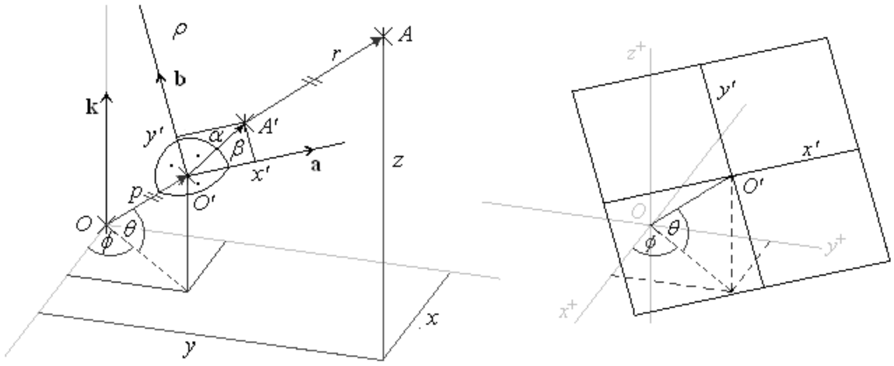

Figure 1. Orthographic parallel projection $A'(x', y')$ *of point* $A(x, y, z)$

Remark: When the author explains this theory, he uses a transparent plastic sheet as the projecting plane, a wire model of the *xyz* coordinate system, and two wires as vector $\mathbf{OO'}$ and the projection direction. The meaning of angles ϕ and θ is made clear by moving the system of (sheet + wire for OO') in the model of the *xyz* coordinate system. Then, a carton cube is placed in the *xyz* coordinate system so that the wires for axes *x*, *y*, *z* are inserted through the holes in the centres of the faces (Fig. 2a). The system (sheet + wire for OO') is set up so that angles ϕ and θ are about 30 and 20. Then, the vertices of the cube are projected on the sheet using the wire for the direction. Linking the projections of the vertices properly gives the projection of the cube.

Projecting a cube in Excel

Let ABCDEFGH be a cube of edge length *a* with the centre at origin *O* of *xyz* coordinate system and faces parallel to the coordinate planes (Fig. 2a). The application that projects the cube in Excel without solving the overlapping of the faces is in Fig. 2b. Edge length *a* is in cell C6. Angles ϕ and θ are in cells C4 and C5 in degrees, converted to radians in hidden cells J4 and J5.

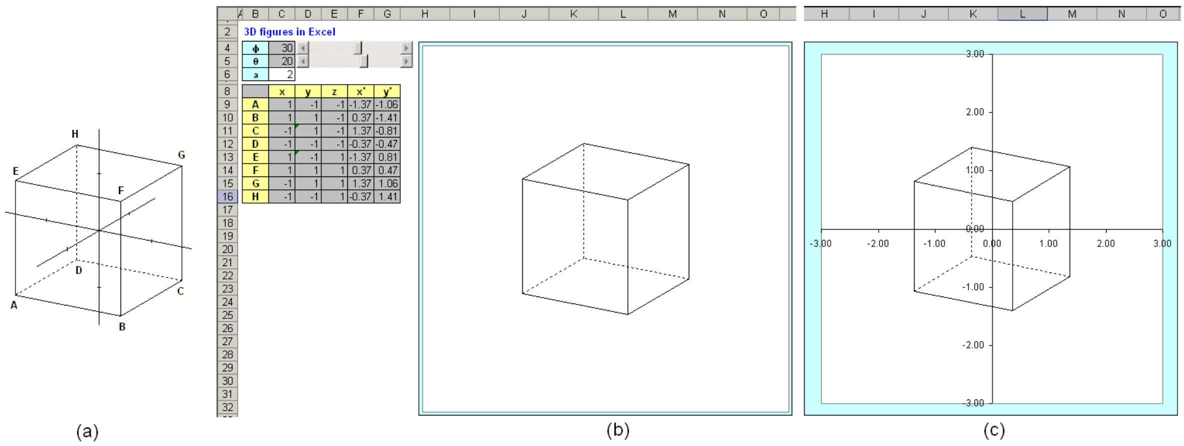

Figure 3. Cube in xyz coordinate system (a); cube with non-solved overlapping of the faces, the chart axes switched off (b) and on (c)

The *x*, *y*, *z* coordinates of the vertices are calculated in C9:E16 referring to C6, which makes the projection sizable. It is C6/2, –C6/2, – C6/2 for point *A*. The x' and y' coordinates of the vertices are calculated in F9:G16. Each edge is drawn as a two-point xy line graph. There are 12 graphs for 12 edges. If an edge becomes invisible when the real cube is rotated, the user can double-click the edge in the chart and change it to dash or white to make it invisible. The maximum and minimum of axes x', y' are set to –3 and 3. Then, the axes are switched off (Fig. 2b, 2c). Angles ϕ and θ are governed by scrollbars. For the first one, LinkedCell is K4, Min is 0, Max is 360, SmallChange is 1, and LargeChange is 5. Then, cell C4 is rewritten by the formula =K4–180. That makes ϕ go from $-180°$ to $180°$ by $1°$ or $5°$. For the other scrollbar, LinkedCell is K5, Min is 0, Max is 180, SmallChange is 1, LargeChange is 5. C5 contains the formula =K5–90.

Solving the problem of overlapping of the faces

The application that projects the cube with solved overlapping of the faces is in Fig. 3. Each face is drawn as a 5-point xy graph going through the vertices of the face where the fifth point merges with the first one. It holds that if a face becomes invisible when the cube is rotated, then the angle between its normal vector **n** oriented out of the figure and the projection vector $\mathbf{s} = \mathbf{OO'}$ becomes bigger than $90°$, so the scalar product **SP** of the vectors becomes negative. On that condition, the face can be made invisible by letting it collapse into point 0 by using function IF. The faces are calculated in separate ranges. The front face is in range B20:E26. Vector **s** is calculated in C18:E18. The vertices are in B22:B26. Normal vector **n** is in C20:E20. Its scalar product **SP** with vector **s** is in cell E22. Cell C22 and D22 contain the same formula =IF(AND($P$13,$E$22<0),0,VLOOKUP(B22,$B$9:$G$16,5)) except for ending …,6)) in D22. The formulas are copied down. Cell P13 contains the value true or false of CheckBox "Overlap". The overlapping works if the CheckBox is checked. The back face is in B28:E34. It is invisible in the left side of Fig. 3 (note the checked "Overlap", the negative **SP,** and the null x', y') but visible in the right side (note the unchecked "Overlap", the positive **SP**, and non-null x', y').

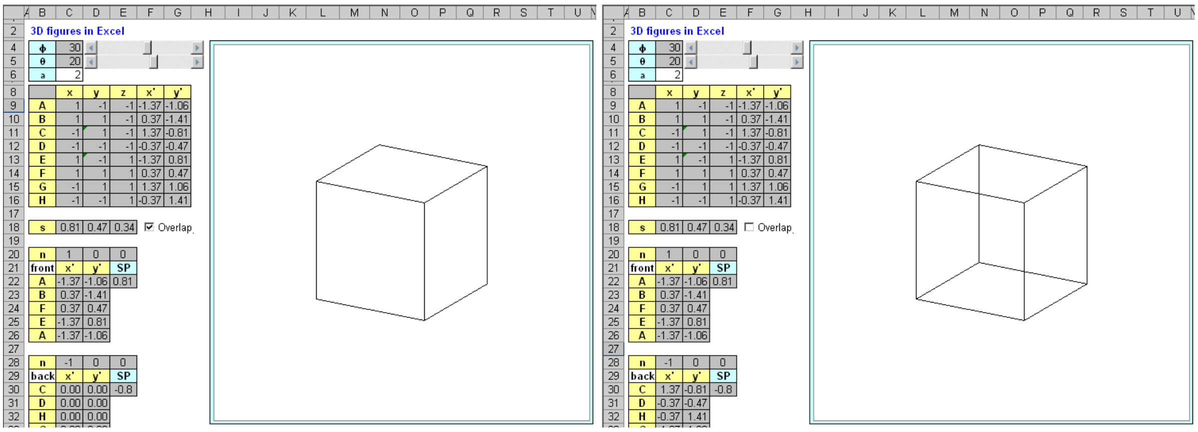

Figure 3. Cube with solved overlapping of the faces

Acknowledgement

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The RoboScratch Theatre: Constructing knowledge with Lego Mindstorms and Scratch through artistic activities

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Abstract

This workshop aims at connecting educational robotics and the Scratch programming environment to the concept of theatre. The integration of a tangible concept, such as that of preparing a theatrical performance can provide a new perspective on problem solving activities through programming environments, such as Scratch and Lego Mindstorms. Art holds an important position within the entire school curriculum, for introducing complex concepts to children (Kindergarten) or even for students' bonding, collaboration and socialization. Within this workshop, the tight connection of theatrical performances and Lego Robots, as well as programming with the Scratch environment will be demonstrated, as means for facilitating collaboration within problem solving activities, thus providing a valuable new perspective for the children, allowing them to develop problem solving and social skills.

Keywords (style: Keywords)

Lego Robots, Scratch, Theatre, Art

Introduction

Educational Robotics is becoming an increasingly researched area, related to the pedagogical exploitation of Information and Communication Technologies (ICTs) in education. The latter is not mainly based on the technological platform/tool used, but rather on the underlying theoretical perspective which allows the utilization of technological characteristics of ICTs, such s recording, representation, management, information processing and transfer. The concept of pedagogically exploiting ICTs mainly involves tasks for the active participation of students and teachers, facilitating interaction among them as well as the creation and/or manipulation of mental models (Mikropoulos & Bellou, 2006). These approaches completely comply with the constructivistic and sociocultural approaches, as they were introduced by Piaget and Vygotsky, accordingly.

Constructivism explores how children construct knowledge, by applying what they already know through their personal experiences to user-centred interactive approaches which introduce authentic problem situations and usually involve collaboration with peers. These approaches allow them to (re-)organize their experiences to knowledge structures (Jonassen, 2000). According to Papert, knowledge construction is more effective when learners are engaged in designing meaningful projects and constructing artifacts. This approach has been established as constructionism and technology provides tools for this design and construction (Papert, 1993).

Educational Programmable Robots, such as Lego Mindstorms, allow the design of approaches which follow the four main principles of constructionism (Bers et al, 2002; Resnick & Silverman, 2005):

- Learning by designing meaningful projects, creating things and sharing them in community
- Using manipulative objects to help concrete thinking about abstract phenomena
- Identifying powerful ideas, tools to think with from different realms of knowledge
- Learning by reflection

These principles are also facilitated by programming environments which allow the design of authentic problems to be solved in a meaningful way. Scratch (http://scratch.mit.edu/) is an environment that allows 4-12 year old students to program computers by eliminating the technical difficulties of normal programming languages. It integrates Logo-like programming, as originally introduced by Papert, but it is also expandable by connecting to Lego and other sensors, thus providing a more tangible and interactive working environment.

Furthermore, art is a core constituent of the school curriculum, especially in Preschool and Primary Education. From Kindergarten, concepts are introduced to children through puppet shows and learners often follow experiential teaching approaches in class by participating in role playing games, similar to a theatrical performance. By this age, children are experientially familiar with corresponding concepts, such as *actor*, *role*, *script*, *performance*. In any case, it is common for young aged classes to organize theatrical performances at the end of the academic period, thus demonstrating to the parents how their children have progressed through the year.

The underlying idea for this workshop proposal is to combine the aforementioned tools and approaches, thus providing more authentic, realistic and meaningful activities for young learners.

Description and workshop objectives

This workshop aims at integrating the constructionistic exploitation of educational robotics and Scratch with the concept of a theatrical performance in an attempt to provide a more meaningful environment of teaching activity design for the children. In fact, computer programming through the Scratch environment follows the actual design of a theatrical performance. The programmer has to guide characters (actors) who talk, move and interact on a stage. As a theatrical director, he/she has to properly place the actors on the stage, coordinate them and design the scenery. As a script writer, he/she has to write the script for all these actors. All the above is implemented by joining puzzle-like pieces.

The idea is that teachers as educational designers can exploit the children's experiential familiarization with theatrical performances and movies in order to provide a meaningful environment for the children to be involved in problem solving activities through computer programming and robots' constructing.

The core objective of the workshop is to introduce the aforementioned concepts to the participants and clearly demonstrate their interconnection on both a theoretical and practical level. The objective of the workshop is in agreement with researches results (Rusk et all, 2008), which suggested strategies that have been successful in engaging a broad range of learners. According to them, robotics projects must focus on themes, not just challenges, combine art and engineering, encourage storytelling and aim to support exhibitions, rather than competitions. Also combining craft materials, mechanical parts, and programmable devices can inspire both girls and boys to think more creatively about what is possible and what they want to create (Rusk et all, 2005). New technology, called the PicoCricket (http://www.picocricket.com/), that supports previous strategies developed, which enables students to design and program artistic creations that integrate light, sound, music, and motion and also exploit familiar objects and material.

By providing hands-on group activities, the participants will be able to understand this interconnection in an experiential manner. Having completed the workshop, the aim is for the participants to be able to design their own teaching activities.

Finally, ideas discussed within the workshop will be collected and expanded, providing material for a collective book volume.

Workshop outline

The workshop will be divided into three (3) phases. During Phase 1, the organizers will introduce the corresponding concepts through short positional presentations. Specifically, the connection of theatrical concepts and Robot & Scratch programming will be outlined. Then examples will be presented, outlining the differentiation between organizing a theatrical play with children as actors, as opposed to robots as actors. Also the concept of directing a theatrical play as a method of debugging program scripts will be discussed.. The duration of Phase 1 will be 40 minutes.

During Phase 2, the participants will be divided into small groups and attempt to design their own activities, based on the examples presented during phase 1. They will have the opportunity to construct and program Lego Robots, as well as work in the Scratch environment. Participants will use Lego NXT Mindstorms to implement a theatrical play, which requires independently robot development, but also robot motion synchronization and participants' collaboration. Familiar objects and material will be used for art creations and robot suits. Assistance will be offered by the organizers constantly. The duration of this phase will be 45 minutes.

During the final phase, the groups will have to present their educational design. Then, a concluding discussion will follow in order to sum up the workshop and organize a post-workshop collaboration among the participants which will include the construction of a small Community of Practice and a collective volume of educational activities and theoretical perspectives.

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Knowledge construction in the Bebras problem solving contest

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Abstract

In this workshop we will try to discuss the question: how can a computer science contest contribute to knowledge construction? Usually a contest tests already learned knowledge and skills. In the case of the Bebras contest no pre-knowledge and no specific skills are required by the students (age 10-19). While participating in the contest they can learn about different aspects of computer science concepts, like information representation, structures, algorithmic aspects, automation aspects, etc. While trying to solve given tasks the students may construct their knowledge that is related to the presented problem sets. The quality of the problem set is most important for giving the right stimuli for learning. That is why we will discuss, based on some given Bebras tasks, the attributes of tasks that allow a maximum effect on the learner's knowledge construction.

Keywords

Computer Science Concepts, learning Informatics, learning by contest, knowledge construction

Seymour Papert wrote how children learn in a particular context using their own and from others created objects (Papert, 1993). A main point of constructionism is not to accumulate more and more knowledge, but to learn different methods and ways of targeting information and to select and absorb the abundance of knowledge and using them effectively to create new knowledge. The constructionistic learning can be conducted in different ways. We will concentrate here on the way via solving tasks while participating in contest.

„Bebras" (Lithuanian for beaver) is an international initiative to promote Computer Science (CS) among teachers and students aged 10 to 19 (http://bebras.org). The Bebras method is to organize easily accessible and highly motivational online contests in many countries (Dagiene, 2008; Futschek, 2009). Each country-wide contest asks small and interesting questions that can be answered without prior knowledge about CS, but are clearly related to CS concepts and require computational thinking skills in information representation, discrete structures, computation, data processing, as well as algorithmic concepts. That is, any Bebras question can both demonstrate an aspect of CS and test the participant's CS-related talent. Since 2004, Bebras has quickly spread across Europe and in 2011 there were 370,000 students participating; thus, it is the non-school activity in CS education with the largest audience.

Each country provides a set of task proposals, and the whole pool of proposals is then discussed at an international workshop. The national contest organizers make up their national task set from this pool. A subset of the task pool is determined to be mandatory and must be used in all national Bebras contests.

The International Bebras Contest is a very ambitious contest. It does not test pre-knowledge or specific skills learned at school. In contrary there are only problem solving activities, no pre-knowledge is necessary. The students may learn aspects of informatics concepts by solving Bebras tasks. The better the problem-solving skills the better are the results. The more tasks the students have worked on the more they have learned. A very important aspect of the Bebras tasks is the construction of knowledge in CS. The tasks should have the character of a game and not the characteristic of an examination. This workshop will enable participants to explore, understand and evaluate the Bebras tasks and to find out how they involve concepts of informatics.

The contest is for all lower and upper secondary school pupils, divided into four age groups. Students have to solve 18 to 27 tasks on different levels within 40-60 minutes, entering answers via computer. They do not require a specific topic knowledge, but they require to be able to reason with common structures in the CS/informatics canon.

The tasks involve concepts such as algorithms (sequential and concurrent); data structures (heaps, stacks and queues, trees, and graphs); modelling of states, control flow and data flow; human-computer interaction; and graphics. Students do not formally study these topics, instead, the topics are introduced implicitly by letting the students thinking about interesting problems. A "narrative cover story" is used to relate the tasks to an underlying topic.

List of Content:

Contest tasks that inspire thinking
Aspects of Knowledge Construction
Outline of "Bebras International Contest on Informatics and Computer Fluency"
Learning through a contest
Example tasks that support knowledge construction
The challenge to design such tasks
The experience of some participating countries

Duration of workshop: 2 hours

Expected audience:

IT teacher, teacher educators, educational scientists.

If there are secondary school pupils of local schools available we can even perform a 40 min contest with them during the workshop.

Example of a Bebras task

Graph of a map

Maps can be easily pictured as graphs. In such a graph every node is a country and the lines between the nodes mean that they border each other. The picture shows a graph of a map with seven countries. Jim has to find a map that fits the given graph. He has four options. Can you help him find a map that matches the graph?

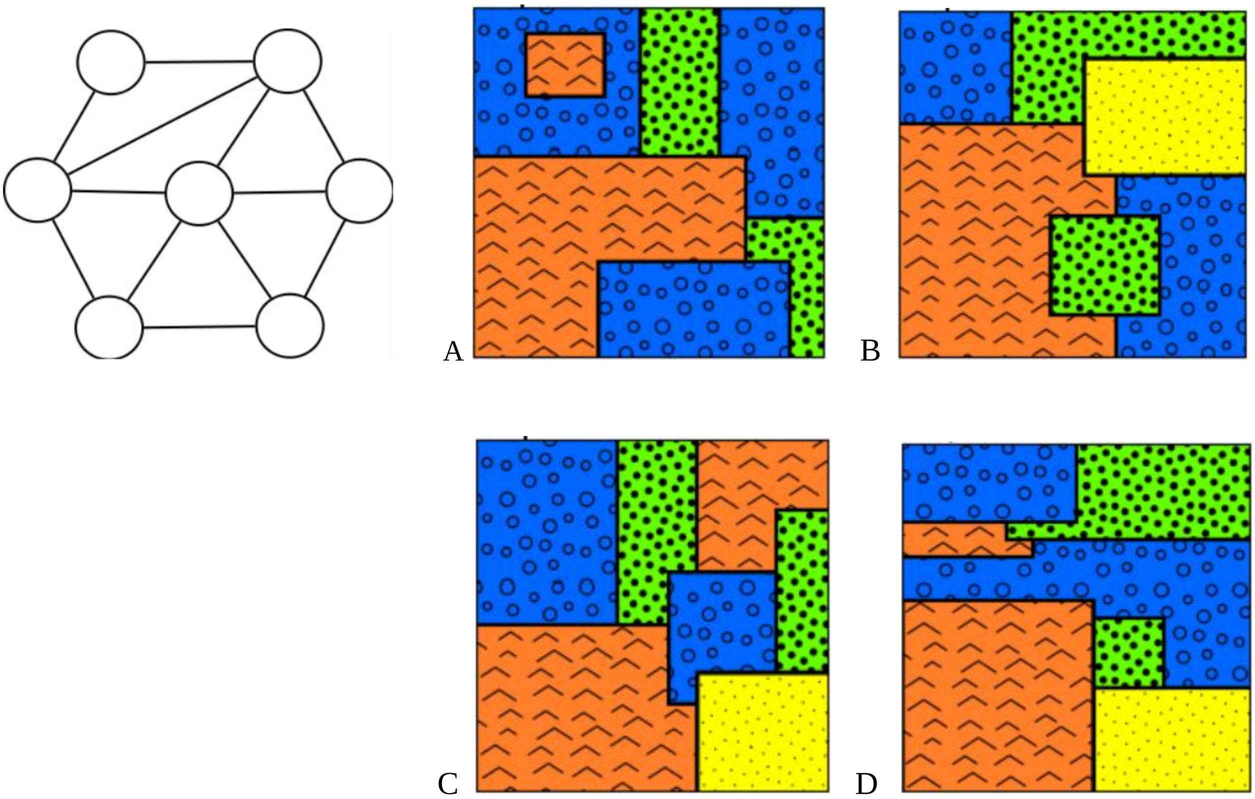

Figure 1.The graph and multiple-choice answers

While solving this task the students learn that a graph may represent the neighbourhood relation of a map of countries. They also develop strategies to find out which map relates to a given graph. In this way the Bebras task helps constructing knowledge and thinking skills that are closely related to Computer Science.

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The Snap! Programming Language

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Abstract

This workshop presents SNAP! (http://snap.berkeley.edu), a browser-based reimplementation of BYOB (Build Your Own Blocks). SNAP! is an advanced drag-and-drop programming language inspired by Scratch (http://scratch.mit.edu), aimed at teen and adult learners.

Besides greatly improved speed and reliability compared with the earlier BYOB, this version does not require software installation, and includes advanced features including first class continuations.

Participants will learn to use the language, with particular emphasis on features new since the 2010 BYOB workshop such as object oriented programming and first class costumes.

Keywords

SNAP!; programming language; browser-based; recursion; higher order functions; object-oriented programming; continuations; everything first class

Workshop Objectives

This workshop is related primarily to Theme 3A (Constructionist Technologies) but also has connections to Themes 1A-C (teaching themes) because SNAP! is used in the “Beauty and Joy of Computing” curriculum and teacher preparation program.

Workshop participants will write short programs in SNAP!, starting with simple blocks and progressing through recursion, higher order functions, and object oriented programming. They will learn to be able to write programs in SNAP! and to teach using the language.

Outline

- Building simple blocks (SQUARE)
- Blocks with inputs (SQUARE <size>)
- Reporters and predicates (EVEN?)
- Recursion (VEE, TREE, sentence generator)
- Higher order functions and lists (MAP, KEEP, COMBINE)
- Sprites as objects, inheritance (SINE, parallel TREE)
- Continuation (nonlocal exit, threads)
- Discussion of the use of SNAP! in the Beauty and Joy of Computing curriculum

Keywords

SNAP!; programming language; browser-based; recursion; higher order functions; object-oriented programming; continuations; everything first class

Constructing microworlds with E-Slate

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Description and Workshop Objectives

This workshop is about E-Slate is platform consisting of tools and components that allow end users to create their microworlds. E-Slate has adopted a black and white box approach (Kynigos 2004) in that it provides technically efficient black box components as higher – order building blocks to build software consisting of component configurations. These components are designed to be as generic as possible. E-slate microworld construction is not only based on the constructionist paradigm through building component configurations, but also on the connectivity metaphor, providing authors with multiple metaphors for connecting and thinking about component connections. Main component configurations can be organized in the following categories: a)data handling, b)turtle worlds, c)science simulations and d) gis (data bases connected on maps). ETL research group the constructs of halfbaked microworlds (Kynigos 2007) and of construction kits as instruments for engaging end users in microworld construction. A number of microworlds have been also developed by teachers, researchers and students covering a wide range of scientific fields (from mathematics to language). In the workshop participants will have the chance to use, play and deconstruct microworlds, halfbaked microworlds and microworld kits.

Outline

- Deconstructing a microworld: presentation of the main E-slate characteristics (components, authoring tools) by workshop organizers
- Hands on microworlds: participants open and play with microworlds already developed with E-Slate
- Hands on half-baked microworlds and construction kits: Participants will engage in changing a halfbaked microworld of their selection or develop a new microworld with a construction kit
- Discussion on the process of microworld design with E-Slate

Expected outcome

Familiarization with E-Slate, acquaintance with E-Slate functionalities through concrete examples, change and enrichment of halfbaked microworlds and construction kits.

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3d Math: creating and dynamically manipulating 3d geometrical figures

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Workshop aims and background Projects

The workshop aims at introducing the participants to a 3d Turtle Geometry environment called 3d Math and at generating discussions about its added pedagogical value in teaching and learning concepts related to 3d geometry. 3d Math has been developed within the two major European Projects: ReMath[i] and METAFORA[ii]. The organisers of the workshop (the Educational Technology Lab team) have participated in those two Projects and carried out research with 3d Math in different educational contexts, feeding with their findings the pedagogical design of its features and functionalities.

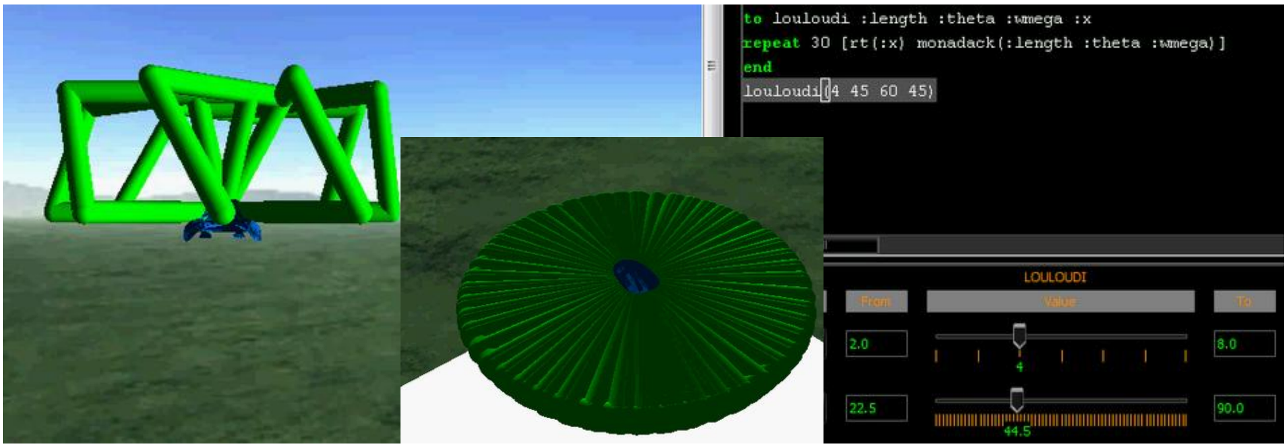

Figure 1: Students' constructions with 3d Math – The "Flower" procedure

The 3d Math Digital Tool

3d Math is a programmable constructionist environment that allows the creation and dynamic manipulation of 3d geometrical figures. These are generated in the environment's virtual 3d space when running Logo procedures and commands. Inheriting elements from "E-Slate 2d Turtleworlds" and building on the idea of multiple linked mathematical representations (Kaput, 1992), 3d Math integrates symbolic notation -in the form of Logo programs– with the dynamic manipulation of 3d geometrical objects through the use of specially designed Variation Tools (Kynigos & Psycharis, 2003). The dynamic manipulation through the Variation Tools takes places by sequentially changing the values of the variables included in the Logo procedure that initially creates the 3d figure. The dynamic manipulation of the camera's viewpoint may allow the students to navigate around and through their constructions, possibly providing new ways of visualizing 3d space and the figures inside it. The camera's viewpoint may be manipulated both with regard to its position and direction inside the virtual 3d space.

Workshop format and methodology

The workshop's format will be based on a discussion-oriented organization that will also include introductions/presentations coming from the organisers and hand-on activities to ensure that all participants have the experience of working with 3d Math and its features. The working methodology for the workshop is made up of the following steps:

1. The ETL team will give an overview of instances of 3d Math's implementation and use in different levels of education (primary, secondary and tertiary) and contexts, trying to highlight in parallel its distinct features and its constructionist theoretical underpinnings.
2. The instances presented will then be used by the participants as 'half –baked' microworlds (Kynigos, 2007). Half-baked microworlds incorporate an interesting idea and at the same time are buggy enough to invite users to change parts of them and create new artefacts, possibly distinctly different than the initial ones. These microworlds will be mediated to the participants as unfinished artefacts which need their input. In particular, three half-baked microworlds will be presented in the beginning of the workshop:
    - *The Revolving Doors Microworld*: The Revolving Doors microworld is designed to help students at the end of primary or lower secondary school level make dynamic links between everyday experiences with angles in space and the use of mathematical representations to construct simulations where angle plays a significant role
    - *The Helix Microworld*: In differential geometry a curve can be replaced by a linear approximation, that is tangent lines. In this microworld the Turtle's moves and turns in 3d space produce these tangent lines. Using Logo programming, the students (even the young ones) may symbolically express how the Turtle should move and turn to approximate curves in 3d space. Putting in use their intuitions, students are expected to generate meanings about curvature even before they reach the complicated formulas of differential geometry.
    - *The Twisted Rectangle Microworld*: The Twisted Rectangle half-baked microworld builds on the idea of giving students -from the very beginning- a genuinely 3d geometrical figure, instead of a 2d shape that in the way transforms into a 3d, as they "discover" the 3rd dimension. To be more challenging, the Twisted Rectangle generated when running the Logo procedure is not quite what is expected, as the shape that appears is an open, instead of a closed one. Being incomplete by design, the Twisted Rectangle microworld invites students to deconstruct the Logo procedure responsible for creating the "deformed" 3d figure, and reconstruct it according to their own understandings of the 3d geometrical properties such a figure would entail.

   As the organisers present those microworlds, the participants will be able to also run them in their laptops or PCs available at the room the workshop will take place. The organisers will provide the Logo codes.
3. After presenting the half-baked microworlds, the participants will be asked to choose between those three and work with it for about 40 minutes. As the microworlds will be presented as fallible artefacts, we expect the participants to use 3d Math's features and

functionalities to explore them and eventually to create their own artefacts using the original constructions or parts of them as building blocks. If the number of participants present allows it, there could be some group forming, within which its members could present and share the artefacts they create.

4. In the end, the participants will be asked to reflect on their learning experience with 3d Math and take part in an open discussion (20 minutes) that will address the issues described in detail at the "Expected Outcomes" section of this document.

   The organisers of the workshop will keep notes and distribute them afterwards among the participants in a Google Doc form. The Google Doc will be accessible for everyone so as to allow changes and new ideas to feed the workshop's outcomes.

Expected outcomes

The workshop will engage the participants in free pedagogical exploration and reconstruction of the above mentioned half-baked microworlds. The aim is to bring in the foreground issues concerning (a) the mathematical nature of 3d geometrical objects and how these may be dynamically manipulated and transformed in mathematically meaningful ways (b) the ways mathematical concepts can be integrated with spatial navigation and orientation in 3d virtual environments and (c) how 3d computational environments can be exploited in didactical/educational design. The above issues are expected to provide a basis for fruitful reflection among the participants on the pedagogical added value of 3d Math and other 3d Turtle Geometry Environments as well as on the future directions for the design and pedagogical exploitation of 3d Math and other 3d environments (e.g. Dynamic Geometry Environments).

Keywords

3d Math, Turtle Geometry Environments, Turtle metaphor, added pedagogical value, half-baked microworlds

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Explore the Next Generation of Scratch

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Millions of young people around the world are using Scratch to create and share interactive stories, games, animations, and simulations. In the process, they are learning to think creatively, reason systematically, and work collaboratively.

In this hands-on workshop, you'll get a chance to try out the next generation of Scratch, called Scratch 2.0, which will be launched later in 2012. Scratch 2.0 brings programming to the "cloud", enabling you to create and edit Scratch projects directly in the web browser, opening up new opportunities for creativity and collaboration.

With Scratch 2.0, you can:

- share sprites and scripts between projects, using the new "backpack" feature
- store "persistent data" in the cloud to create online surveys and high-score lists
- create projects that react to movements in the physical world, using new camera programming blocks
- build new programming blocks and share them with others

Come to the workshop to explore these new features, learn about the ideas underlying Scratch 2.0, and discuss strategies for using it in your educational settings.

Metafora: Learning to learn together during explorations with microworlds

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Description and Workshop Objectives

This workshop is about an on-line System, called Metafora, which integrates microworlds with two shared workspaces: one for planning and reflecting??? (Planning Tool) and one for discussing and exchanging ideas (LASAD). The Metafora System also provides intelligent support to teachers and students on issues related to the concepts they negotiate in the microworld, to the plan they create and to the discussion they engage. Workshop participants will use the Metafora System undertaking the role of teachers or students. They will be asked to collaborate and discuss with other participants through the Metafora System, engage in short tasks in mathematics, environmental education and physics and reflect in the learning to learn together skills supported by the tools and the intelligent support provided by the System.

Outline

- Presentation of short tasks in mathematics, science and environmental education: Participants are expected to choose one task
- Assigning different roles to participants (students, teachers)
- Plan the course of action to address the task selected (Planning Tool)
- Enact the plan working with the microworlds
- Use the shared discussion space (LASAD) to ask for help or discuss ideas and constructions
- Reflection with participants about learning to learn together with the Metafora System

Expected outcome

Familiarization with the Metafora System, analysis and reflection on learning to learn together with the Metafora System, discussion for the potential of the system to be implemented in the classroom.

Keywords

Learning to learn together, planning, collaboration, experimentation, intelligent support, referable objects, microworlds.