A Constructionist Toolbox in the Upper Elementary Classroom - 10 Years of Integrated Robotics Projects

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Abstract

This paper presents the evolution of successful robotics projects and processes used in a regular education classroom over the last ten years. This classroom is in Smithfield, Rhode Island, USA. The process and activities used, with students having no prior robotic knowledge, provides them a "toolbox" of knowledge and skills needed to construct meaningful learning and to demonstrate that learning to others. Their learning is applied and authentic, as is the assessment, and culminates in presentations of their projects meshed within an annual theme at the end of the academic year. The process is hands-on, differentiated and integrated throughout the curriculum. Robotics projects that have been made possible through these processes include Marionettes, Insects, Electronic Jewelry, Aboriginal Art and Landscape, Fractals, Monarch Butterflies, Cole Porter's 'You're the Top,' Feeding Frenzy Critters, Green versus Mean, Geology Bots, and Leonardo DaVinci inspired inventions

Keywords

Educational robotics, robotics in the classroom, integrating robotics, robotics

Background

Robotics in school setting has been pursued for the better part of two decades. In recent years, here in Rhode Island, the trend has been for robotics classes to move from being integrated in the public school classroom to after-school, home schooled, private schools or club activities. Reasons for this transition are varied but have been justified based on the increased time required for mandated State testing and the expenses involved with purchasing the latest technologies. However valid these reasons may be or appear to be, the authors have found that the youngsters, particularly at the elementary level, truly enjoy the learning environment that they experience while 'doing' robotics and that they do learn. Robotics is a verb not a noun. It is not taught as a subject area but as a way to actively engage in learning. How it is integrated across the content areas in the classroom is key to its success. The constructionist environment described here has been successful and has evolved over many years. Most of the students have not had any experience in building, modeling or sharing/explaining their learning.

So, we whole-heartedly agree with Papert (1980) who said, "But children, what can they make with mathematics? Not much. They sit in class and they write numbers on pieces of paper. That's not making anything very exciting. So we've tried to find ways that children can use mathematics to make something—something interesting, so that the children's relationship to mathematics is more like the engineer's, or the scientist's, or the banker's, or all the important people who use mathematics constructively to construct something."

What we do

The processes and actions that we instill in the students allow each student to build and to demonstrate their learning. Students are given "play" time to naturally experience materials and concepts. Students have time to explore and experiment with their ideas with the self-focus of 'can I get my robot to do such and such?', 'how did you do that?', or 'let's try this.' This playtime allows for reflective writing that is just that - students reflecting on what they observed and internalized, the problem solving concepts tried out, results obtained, and the evidence of burgeoning appropriate vocabulary and teamwork.

When students write about what is personally meaningful to them, as opposed to an assigned prompt, the writing is much better in quality. It has been described as 'technical' writing about robotics or robotics-related activities but we say that the writing is 'purposeful.'

Their weekly writing homework for robotics is kept in a yearlong binder. It is part of the Project's presentation, which culminates at the year's end state wide event-Robotics Park. Students are told on the first day of school about this expectation of participating in Robotics Park (2010), http://www.risf.net/RoboPark.htm, again, giving their work purpose. For eighteen years hundreds of students from Rhode Island have displayed their creations at this annual spring celebration of the Rhode Island School of the Future. The students present and demonstrate their projects in a given category whether Robotic Animal Design, Robotic Interactive Device, Chain Reaction Machine, the Robotics Park Parade, and/or Creature Feature Feeding Frenzy.

At the start of the school year the overall Project or big idea is announced and discussed with the students. A theme or frame for the Project is selected for their constructions. Discussions are open and their initial ideas are recorded and saved for a later day. Once the overall theme has been shared, their journey starts with learning and utilizing the tools in the toolbox. It should be mentioned that while we know the tools and the process to the end, we don't know what obstacles or rather problem-solving opportunities that we'll meet along the way. Hence we, the authors, learn and demonstrate to the students how we learn. Then they realize that they have partners to help them and partners willing to accept their ideas. The authors are more like coaches and facilitators that allow for learning that is more lateral as opposed to top down teaching methods.

The students are presented with an open-ended Project idea and a schedule when the Project must be completed. This is a real deadline and it is usually students' first time with a long term project as well. In all their endeavors throughout the year they are asked how they advanced the Project and to record their progress and contributions.

The Toolbox; what and why

To construct, one needs tools. Table 1 lists the "tools" that are used and what they offer. LEGO® is the medium of choice because of the high degree of design engineering that goes into the product and the mathematical relationships that are built into the pieces. They are colorful, tactile and playful and are highly familiar to students. As the students' experiences grow, materials other than LEGO® can and are often integrated to the mechanized creations.

Table 1. Tools and techniques used in creating designers of robots in the fifth grade

Tool	Why
#1 Three piece LEGO® Activity	Effective communication, common language, basic building; Bottom up/orientation, mathematical arrays
#2 Klutz Crazy Contraptions: A LEGO® Inventions	Extending vocabulary, following directions; Gaining understanding of which pieces fit together; Choosing a challenge, documenting and letter writing

Tool	Why
Book (Klutz)	
#3 Gearing	Simple and compound concepts, model building, gearing up/down, fractions, gear ratios, torque, friction
# 4 Fan Project	Introducing motors and where they go. Controlling motors with programming via Dacta Control Lab Logo. Introduction to sensors as control mechanisms. Words have meaning and connections to real devices via the interface box. Logo natural language is very helpful.
#4 ZNAP	Compound parts allow for bigger, quicker models. Pieces can interface with regular LEGO®.
#5 Adding Motors	Re-visiting Klutz book to take mechanical to mechanized devices sometimes under control of sensors.
#6 B-I-Y site	Exploring options for finding web resources to assist team. Choose and build a device to share with class See how parts can work together. Economical use of parts to create movements and behaviors. http://www.build-it-yourself.com/biy-blocks/localhost/index.html
#7 P.I.E. site	Same as above. PIE modules can be found at: http://www.pienetwork.org/a2z/m/modules/
# 8 Robotic Kits	Mindstorms RCX programming in Robolab and MicroWorlds (LCSI, Terrapin) Mindstorms NXT programming in NXT-G Handy Crickets programming in Cricket Logo and MicroWorlds PicoCrickets programming in Logo Blocks
#9 Programming in conjunction with a design engineering process	Create subassemblies and devices for prototypes Demonstrate basic forward, backward, left and right Which language will suit the Project the best? NXT, Pico Cricket, any Logo, Robolab, MircoWorlds (LCSI, Terrapin) Sensors- controlling variables. Choosing Project events.
#10 Ancillary materials	Finishing the robot-“dressing the skeleton” Backdrops, banners, schedules, brochures

TOOL #1 Three-piece LEGO® Activity

We start with the 3-Piece LEGO® Activity. Though deceptively simple, the activity is quite powerful. It quickly illustrates the need of a common language by which we can all communicate and understand each other. Students choose a partner and small bins of just LEGO® bricks in different sizes and colors are given to each team. A divider/carrel is placed so that Student A can choose any 3 pieces of LEGO®, stick them together in a desired configuration and then write the directions for how to build it and hand it to Student B. Student B also chooses, builds and writes directions. Then the carrel is removed. Each student now tries to build using only the directions written by the other student. Even though students have been told not to say anything or point at a piece, they find it hard not to do so when they see their partner unable to build from directions that are usually very vague and not precise. They usually write as follows: ‘get the big grey piece and stick it under the small green one and put the yellow on top and you are done.’

When students can speak, the discussion of what went wrong becomes quite lively. She didn’t know what I meant! It was right there! He picked up the wrong piece. A mini lesson is given on how LEGO® is described mathematically such as 1x6, 2x8 [Hayward (1996)]. This lesson connects their previous abstract knowledge of multiplication and mathematical arrays to the concrete LEGO® pieces along with the importance of orientation terms, such as horizontal/vertical, for a starting point. Then the process is repeated. Students are now able to follow one another’s written directions.

TOOL #2 Klutz Crazy Action Contraptions

Klutz Crazy Contraptions: A LEGO® Inventions Book by Rathjen (1998) kit contains about 70 LEGO® technic pieces and gives visual directions for making several "contraptions" and three challenges. Students again choose a partner and choose one of the listed challenges, such as: Using only the pieces in the kit to create letters of the alphabet past the letter 'r'; can you create a bridge greater than 42 inches that can be held by the ends without breaking?; can you construct a tower taller than 40 inches?

Students have to check their kit against the inventory checklist, actual sized, so the 1:1 mathematical correspondence is there. All the pieces are labeled, so the students' vocabulary is extended which is evidenced by their homework. And then the fun (problem solving) begins. No one's first attempt is perfect and they repeatedly try to better their results even at recess time. They feel successful when they have "beaten" the challenge as stated in the kit. Then they are told that previous students are the World Record Holders. This is enough to motivate some students further. Each team shares their solutions with the class and what they have learned. Each challenge has a focus; the alphabet challenge is creative and parts do not have to be attached to one another, but you need an economy of parts to create more letters and a complete alphabet. The tower challenge focuses on stability and having a sturdy base thereby sacrificing parts to create a wider base but this trade off impacts how tall it can be. The bridge challenge focus is on flexibility and weight so the design will not fall apart when lifted by its ends. Students will encounter these same issues (creative problem solving, economy of parts, stability/robust design, and weight) throughout the Project. Students then write to the Klutz Company and tell of their results.

TOOL #3 Gearing

Students in teams of 2 or 3 build a wall of technic beams and place various axle-gear combinations in the wall. They explore the connected movements and try to have every gear move when only one gear is driven by hand. Questions arise such as how many different size gears do you see? How do you measure gears? What sizes so they come in? What are the differences? Do any behaviors that catch your eye? After such exploration the idea of meshing gears is introduced. Then each team is asked to complete the following grid with a 'yes' or 'no' if the gears mesh along a beam.

Gears	8 teeth	16 teeth	24 teeth	40 teeth	
8 teeth					
16 teeth					
24 teeth					
40 teeth					

Why do some gears mesh well and others not? Are there any two gears that never mesh in any way? The terms for a driver gear, driven (follower) gear, and idler gear are explained. The motions of adjacent gears are gear ratios are discussed. Extensions to pulleys are made. Once simple gearing and its relationships are understood the students move on to the compound gear train. They build a 27:1 compound gear train using 3 combinations of 8- and 24-tooth gears. Torque and speed trade off are seen and felt and the students seem to understand the powerful and 'slow elephant' versus the reduced load that a 'fast cheetah' can carry.

TOOL #4 ZNAP

ZNAP is a discontinued LEGO® product. It looks very different from traditional LEGO® but still has the capability of interfacing with other LEGO® pieces. Many parts are compound parts (braced rectangles and curves) as opposed to simple one-element pieces (1 x 8 beams). Students discover that they can build something quite large rather quickly like a lawnmower. ZNAP parts are grouped together in bins and the design booklets are again in a visual format.

Students now have to designate a "parts person" to get all the ZNAP pieces necessary to build what the team has chosen. Some of the items that can be built have a motor powered by a battery pack and this is our focus for this activity. Cars on tracks, helicopters, and airplanes are popular choices. A wire to a battery pack tethers these first "robots" and students observe that there is only one speed. One student observed that his car kept jumping the track and that if he could reduce the speed, the car would stay on the track and thus a segue to programming.

The next few tools are worked concurrently in the classroom.

TOOLS #5 Motorizing / #6 BIY/ #7 PIE / #8 Robotic kits/#9 Programming

After working with ZNAP, which has motors, students have discovered that the motors on a battery pack were limited to one speed. So motors themselves are not the answer to creating a robot, programming movement and using sensors are the keys. Now is the time to build some subassemblies and simple devices. Dividing the class and working in small groups, students are given tasks to do within each group. Some teams are given directions to build different subassemblies. Some teams look through the online web resources at B.I.Y and P.I.E. and choose a device to build. The teams are helped with building and programming as necessary. Sharing at the end of each of these sessions is critical because everyone is doing something different but all want to know what their peers are doing. It is also expected that all teams help each another as needed. Models are kept as an "idea bank" for the Project.

These sessions evolve to further work exploring the sensor options available. Lateral learning spreads like wildfire when one team knows how to make the robot find a line, "speak" or play music. They instantly become peer teachers to the other groups. The "ooh factor" is a powerful motivator. The great part is that every group has a new bit of information to share with the others as well. Critical mass has occurred. Project focus can begin. They are ready to apply and synthesize their knowledge and use their tools.

Tool #9 Programming / #10 Ancillary

The design engineering process is continual and ongoing, as students now have chosen the event they wish to do for Robotics Park whether Interactive, Feeding Frenzy, or Chain Reaction Machine among others. Also much class time is needed to produce all the written research, publications, schedules, invitations, brochures and background artwork needed to showcase their work, as well as integrating math and language arts along the way. Robots may need to be made to look like a fairy, a Monarch butterfly or the Mona Lisa so students are not limited to just LEGO®. Art materials need to be customized for each of the robots in the project. Working with a real deadline is a new experience for students and they do feel the pressure, as the countdown to the big event looms ever closer. Students are always asked to write what they think Robotics Park will be like. And these "before" pieces of writing show nervousness and excitement.

Table 2. Showcase of projects

Grade/Year	Project	Technology / Critical Learning Ideas
5th / 2000-01	Robotic Marionettes	Control Lab; LEGO® and ZNAP
	Stage was 4'x8.' See figure 1. Marionette Stage, Fairy and Knight	XYZ movement programmed in XY-plane with mechanical movement in Z
4th /2001-02	Stage was 10'x14.' See figure 2. Rainforest Backdrop and RI Blue Bug	Control Lab/RCX Six-legged creatures and winged movements
4th/2002-03	Electronic Jewelry [Martin et al (2006)]	Handy Crickets using Cricket Logo

Grade/Year	Project	Technology / Critical Learning Ideas
	See figure 3. Interactive necklace	Designed and constructed interactive necklaces with programmed percent of compatibility displayed on chevron, Boolean algebra
5th/2003-04	Aboriginal Art	RCX using MicroWorlds Logo
	See figure 4A. Aboriginal landscape and Toas	Roving robot finds various toas and send notice to computer via IR signal. Computer via logo draws the particular toa on the screen.
5th/2004-05	Migrating Monarchs	Handy Crickets using Cricket Logo
	See figure 5. Rabble of Monarchs and Migrating Monarchs	Monarchs (line) follow migration paths with wings moving using only 2 motors.
5th/2005-06	Fractal Koch ArtBot See figure 4B. ArtBot picture	RCX programmed to draw a Koch snowflake.
	Chain Reaction Machine (CRM): You're the Top	RCX with Robolab and NXT software, Crickets with Cricket Logo
	See figure 6. Pictures of Mona Lisa and Tower of Pisa	Vertical roulette wheel precision control with NXT motors. Synchronization of CRM to Cole Porter's 1934 hit 'You're the Top.'
5th/2006-07	CRM: James Bond	RCX/NXT
	See figure 7. 007 in Thunderball	Homemade sensors used
5th/2007-08	Feeding Frenzy Pilot Event	RCX and Robolab
	See figure 8. CRM: Green vs. Mean See figure 9. Hungry Critters Jeffy and Curious George Jr.	Novel Feeding Frenzy Challenge designed. Time constrained search of and environment for food (CD) with happy and sad behaviors using only 3 motors and light- and touch-sensors.
5th/2008-09	Rockin' Robots	NXT integration with geology
	Feeding Frenzy	RCX
	See figure 10 of Rockin' Mine fields and Robot Sedimenter in the Grand Canyon	First robots programmed in NXT-G. Students and teachers learning new technology together.
5th/2009-10	Leonardo Da Vinci inspired creations for Feeding Frenzy and CRM.	Parachute, Dragon, Mona Lisa, Catapult, Horse, Aerial Screw, Armored Tank, Battleship Oars, Revolving Bridge. All NXT technology.used.
	CRM: Smart Transportation	Ready for Robotics Park April 10, 2010

Figure 1. Marionette Stage, Fairy and Knight

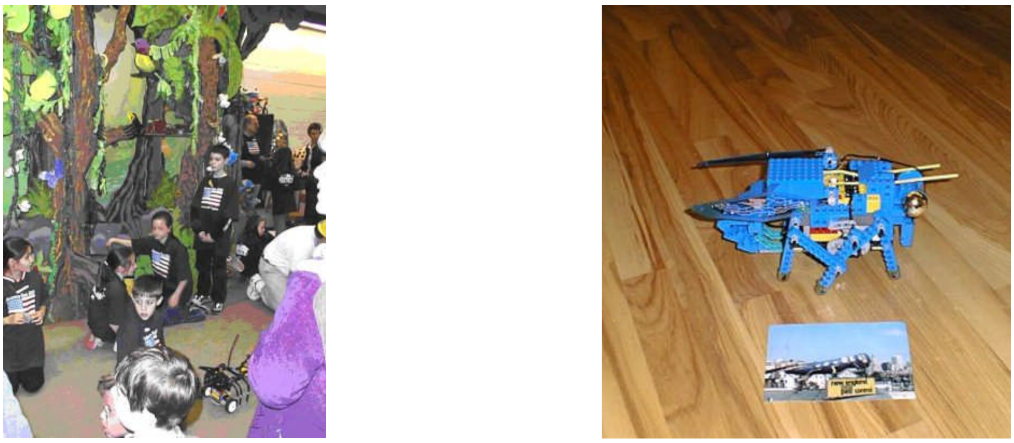

Figure 2. Rainforest Backdrop and RI Blue Bug

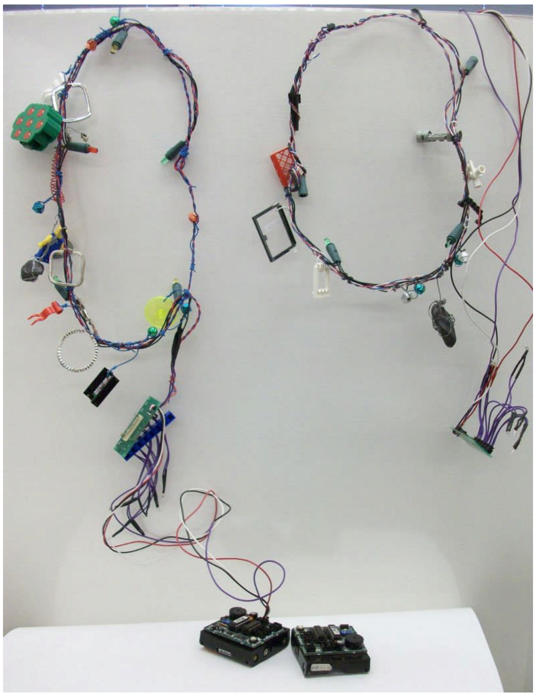

Figure 3. Interactive Necklace

Figure 4. Aboriginal Landscape and Toas and ArtBot

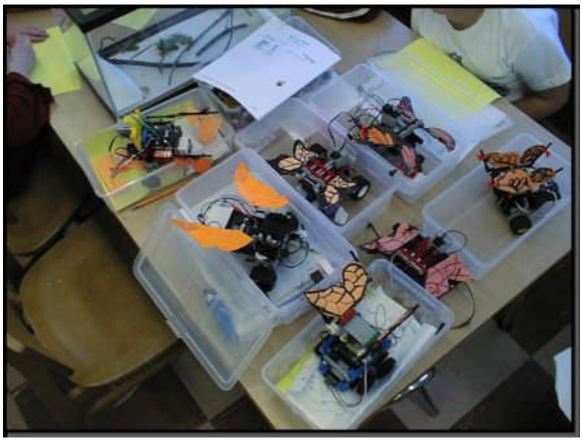

Figure 5. Rabble of Monarchs and Migrating Monarchs

Figure 6. Picture of Mona Lisa and Tower of Pisa

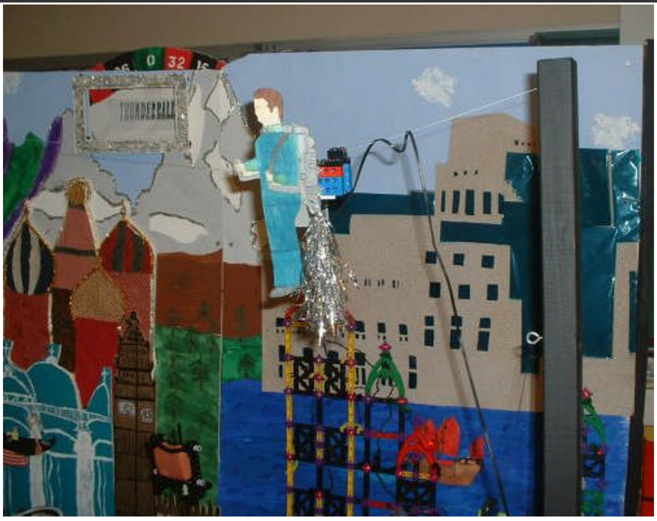

Figure 7. 007 in Thunderball

Figure 8. CRM: Green vs. Mean

Figure 9. Hungry Critters Jeffy and Curious George Jr.

Figure 10. Rockin' Mine Fields and Robot Sedimenter in Grand Canyon

Summary

SCHOOLS often want to showcase problem-solving activities but very often miss offering the students problem solving opportunities that are personally connected to the students. Robotics does offer such opportunities if the creations are open-ended and meaningful to the students. The bottom line is captured by Papert [6] who said, "One of the worst things we do in our schools is compartmentalize. We cut things in bits. One of the worst cuts we make is dividing the aesthetic from the knowledge, from the science. This is a disaster, because the source of the children's energy is largely in two areas that we see here: their social relations and their aesthetic drive. This is what produces the energy, and we cut this off."

Robotics Park showcases their products - the end result of months of hard work. The process that each student has gone through, documented in their robotic binders is their personal journey of success including all the trials and tribulations in between. The binders contain weekly homework differentiated to what each student did that day. The students **must** include a labeled drawing and their robot does not go home with them. The students are so invested in their work that they can draw from memory. They are graded for demonstrating science/math concepts. They self assess their own work by their robot doing what they wanted it to do.Does the robot work?There have been many tears shed and sometimes students want to give up. We let them know what we have asked them to do is not the impossible but the difficult and when that success comes it is theirs alone and no one can take it away from them. The payoff for us as teachers is, when this success happens, that you witness that moment of absolute joy. That is what makes having a constructionist classroom worthwhile; it is a unique educational experience. Robotics Park is their day. Parents and other onlookers are literally amazed at what children can do.

Integrating robotics into our classrooms produces energy, takes time to nurture, requires discipline and teamwork, and gives the students a real-world experience of designing, building and presenting project with a deadline. It is loud and messy, which is disconcerting to adults who think "Oh, they are just playing with LEGO®." Our projects have shown that it is so much more.

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