A constructionist approach to a contested area of knowledge

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Abstract

When the media reports socio-scientific issues, there is routine reference to risk and in England risk has become part of the curriculum in Personal, Social, Health and Economic Education (PSHE), Citizenship, Science and to a lesser extent in Mathematics. It is therefore timely to consider the teaching and learning of risk to young citizens. Yet, risk is a contested concept, not only in the sense that risk is perceived in very different ways according to context, experience and perhaps personal disposition, but also by experts who disagree about what risk is. Thus, although the nature of risk is not yet well established or defined, it is vitally important that pedagogies of risk are developed in response to curriculum requirements and societal need.

This paper reports on one aspect of a study that is developing fundamental ideas about a pedagogy of risk. The approach is to iteratively co-design with teachers software tools that seek to perturb the teachers' knowledge about risk and about the teaching and learning of risk. Conjectures about the nature of the pedagogy of risk are embedded in successive iterations of the software design, according to design research methodology.

In conventional situations, designers have a clear starting point for their work. They are usually working with an established area of knowledge, often mathematical or scientific, and, by conducting an epistemological analysis of that knowledge domain, designers are able to imagine possible starting points. In addition, designers would also typically be able to draw on research about understanding of that area of knowledge. Because risk is understood in many different ways and is a concept that is contested by experts, designing tools to research knowledge about risk raises new challenges.

In this paper, we report on the design of the emergent software in order to tease out the underpinning rationale within which lay principles to inform the pedagogy of risk. We report ten design outcomes, most emerging directly as a result of the contested nature of risk. These outcomes are structured across four fields: (i) decision-making in complex scenarios; (ii) making personal model explicit and computational; (iii) fuzzy quantification; (iv) facilitating co-ordination of dimensions of risk.

We discuss the extent to which this design aligns or contrasts with more conventional microworld design. For example, the outcomes align closely with notions of purpose and utility, phenomenalising, quasi-concrete objects and the design heuristic of fusing control with representation. On the other hand, the approach when designing in a contested area of knowledge seemed to embrace expressive modelling than exploratory modelling as normally found in microworld design.

Keywords (style: Keywords)

risk; probability; constructionism; microworlds; design; mathematics education; science education

Introduction

The media routinely reports socio-scientific issues through reference to risk, often in exaggerated ways. There is a strong societal need for public understanding of risk. Yet, risk is a contested concept, not only in the sense that risk is perceived in very different ways according to context, experience and perhaps personal disposition, but also by experts who disagree about what risk is. Thus, although the nature of risk is not yet well established or defined, it is vitally important that pedagogies of risk are developed in response to curriculum requirements and societal need. In this study, we have been working with teachers to explore their knowledge about risk and its pedagogy. The aim in this report is to examine the design issues raised by the need to design a window on teachers' knowledge about a contested area.

When Papert (1982) talked about the designing of microworlds in his seminal work, Mindstorms, he offered a memorable metaphor in which the designer plants mathematical nuggets of knowledge for the learner to stumble across. But what does the aforementioned designer do when the knowledge to be addressed is contested and therefore loosely defined? This was the task that confronted the research team in the study reported in this paper, when trying to develop pedagogies for the teaching and learning of risk.

When designing for mathematical abstraction (Pratt & Noss, 2002), it is possible to carry out an epistemological analysis to reveal the key powerful mathematical ideas that lie at the root of the topic and to imagine a variety of trajectories that students might take that would imbue those ideas with utility (Ainley et al, 2006). Thus, very young children learn how angle and distance can facilitate drawing and animation through the use of turtle graphics and older children come to appreciate the power of variable when developing projects that involve Logo procedures. Papert's metaphor allows us to imagine this activity as children stumbling across the ideas of angle, distance and variable, not entirely fortuitously since the design of turtle graphics and Logo purposely positions those ideas as controls for the child to use in pursuing his/her objectives. Conventionally, students often struggle to understand the significance of powerful mathematical ideas such as variable in algebra but the constructionist approach promises to generate meaning through purposeful activity. In the above examples, the powerful mathematical ideas are clear, well-defined and entirely meaningful to those enculturated into mathematical discourse but the ideas are often rather less concretised (after Wilensky, 1991) to naïve learners.

In some areas of mathematics there is ambiguity in the mathematics itself though these are rare, at least at school level. Uri Wilensky (1997) has discussed the anxiety of students who are unsure of the epistemological basis for probability. More recently, alongside Dor Abrahamson (Abrahamson & Wilensky, 2007), approaches based around Netlogo have aimed to facilitate learning by bridging across the alternative epistemological interpretations of probability. Probability has in-built ambiguity and experts shift between classical, frequentist and subjectivist definitions according to the problem being solved or personal disposition. Nevertheless, each of those definitions is pretty well worked up and the design task becomes one of seeing the connections (and perhaps distinctions) between the competing views. In other words, an epistemological analysis of probability reveals clearly defined alternative views held by experts in the field and the designer is able to imagine ways of planting those ideas into an environment where they will be used and connected. For example, Abrahamson and Wilensky (2007) describe how their students made connections across alternative epistemologies for probability by tackling the same problem in different ways: by building towers of possible combinations and through collecting data from physical experiments and computer-based simulations.

This paper discusses our solution to a design task that involved knowledge that is fundamentally contested by experts and subject to many personal interpretations. One reaction might be to ask why should learners engage with such loosely defined knowledge. But it so happens that, in our view, the concept of risk, despite its lack of clarity, is of immense significance to citizens. Indeed, risk has been characterised as an integral part of the discourse of late modern society (Beck, 1992). The concept of risk has, in the last few decades, come to permeate real world decision-making, whether in everyday personal and working life, or in policy-making and politics. With the growing demand for awareness and participation at both individual and social levels, with people expected to act as citizens who are accountable for their decisions, an increasing number of choices relating to fields from health and lifestyle to transport to national and international politics involve the need to assess and take some risks.

In fact, the importance of the discourse of risk in public policy is now being reflected across various curricula in England. For example, Personal, Social, Health and Economic (PSHE) education becomes a compulsory part of the curriculum in 2011 and students will study risk as part of that curriculum. The PSHE education association asserts on its website (www.pshe-association.org.uk/):

"Risk-Taking introduces for students the distinctions between positive and negative risk; likelihood and severity… and risk perception… legal and illegal drugs, sex, gambling and anti-social behaviour."

In the Mathematics National Curriculum, 2007 (http://curriculum.qcda.gov.uk/uploads/QCA-07-3339-p_Maths_4_tcm8-404.pdf) in England, teachers are expected to consider situations that involve risk and uncertainty, portraying risk as an adjunct to probability as captured in the phrase: "applying ideas of probability and risk to gambling, safety issues and the financial services sector, and simulations using ICT" (p. 9). The curriculum in mathematics does not make a distinction between probability and risk. The Science curriculum in England is more ambitious and recognises the central importance of considerations of risk in socio-scientific issues and innovative curriculum programmes, such as Twenty-first Century Science (www.21stcenturyscience.org/) have developed extensive materials to support that area of teaching. The attainment target on "Making Science Work" refers to probability and consequence, cost versus benefit, the precautionary principle as well as relative and absolute risk. However, there has so far been almost no principled articulation of the pedagogy of risk to inform the further development of the content.

The contested nature and different perceptions of risk

The essential meaning of the idea of risk is contested and the subject of a diversity of epistemological viewpoints (Adams, 1995; Stirling, 1999). In the media, risk is often quantified and treated as being identical to likelihood (expressed as 1 in n). In other cases, risk is closely associated with the hazard in question: for example, in the London Underground signs reading "Danger: Risk of Death" call our attention to the seriousness of the hazard, making the consideration of likelihood redundant. In complex situations, however, both likelihood and impact need to be addressed simultaneously and trade-offs need to be considered.

In support of what has become standard theory in domains such as Economics, Campbell (2005) has demonstrated through a philosophical argument that a rational view of risk should incorporate both the dimensions of the likelihood of the hazard occurring and the impact should the hazard occur. Standard decision-making theory formulates risk as the product of the probability and disutility (a number quantifying the harm that might ensue from the occurrence of a hazard). However, authors such Tversky and Kahneman (2002) point to the difficulty of assigning a value for probability. The "correct" probability of events is not easily defined, and since "individuals who have different knowledge or hold different beliefs must be allowed to assign different probabilities to the same event, no single value can be correct for all people" (p. 19). The same difficulty applies to the quantification of impact.

The discourse of risk sometimes refers to *actual* risk, as measured and analysed by 'experts' using scientific and mathematical methods, and *perceived* risk, as articulated by the public at large and vulnerable to bias (Kahneman & Tversky, 1979; Kahneman et al, 1982; Stirling, 1999; Sztompka, 1999). Such apparent fallibility explains the experts' rather disdainful view of perceived risk in the discourse on risk. An alternative explanation is that individuals judge risk from a rational perspective in which the data are often tacit and personal (Slovic, 1986); Irwin & Wynne (2006) distinguish between rational expert and rational lay estimates. Estimations of impact are subjective and may be based on sources of information that are unknown to the expert and, in a rational way, lead to a different inference about risk.

On the other hand, the literature contains many studies, which show that judgement of chance is often guided by misleading intuitions, which are rooted in inadequate cognitive heuristics (Konold, 1989; Lecoutre; 1992). Peters (2008) calls attention to how individuals who differ in number ability perceive and use numeric information about risk differently, arguing that highly numerate individuals translate numbers into meaningful information and use them in decisions, in contrast with less numerate people who use other non-numerical sources of information, such as their emotions and their trust or distrust of science, policy-makers and experts. Slovic et al (2000) also highlight how people can read the same information differently when it is given in absolute numbers ("20 out every 100 cases will…") or expressed as a relative risk ("there is a 20% chance that…").

Many other factors also seem to affect how risk is perceived (Kahneman & Tversky, 1979; Campbell, 2006). People tend to perceive the risk of dying in an aeroplane accident as higher than the risk of dying in a car accident; the former can be classified as a more concentrated risk (since many people would simultaneously suffer the consequences should the accident occur). Additionally, risks that are voluntary (that are assumed following deliberation) or associated with benefit from the observer's point of view may often be perceived as lower. Peters et al. (2004) also highlight the importance of deliberation. Research by Finucane et al. (2000) has shown that less deliberation increases the inverse relationship between perceived risks and benefits.

Although citizens in industrialised societies are more affluent and longer-living than their antecedents, concerns arising from public mistrust of those institutions responsible for political decision-making (O'Neill 2002) have prompted personal anxieties and fears in the so-called 'risk society' (Beck 1992; Levinson, 2010), especially when the level of participation of the population is considered low. In this scenario there are pressures for a zero risk approach at the individual level, which reinforce demand for governments to apply the *precautionary principle* at the policy level. *Zero risk bias* can be attributed to a desire for *cognitive closure*, which Webster and Kruglanski (1997) describe as a desire for definite knowledge and the eschewal of ambiguity (p. 133).

Our approach

The fact that risk is regarded as part of PSHE, Citizenship, Mathematics and Science curricula indicates its fundamentally cross-curricular nature. School infrastructures are not well suited to handling issues that do not fall comfortably into one discipline. In our project, Promoting Teachers' Understanding of Risk in Socio-Scientific Issues (TURS[1]), we worked with inter-disciplinary pairings of Mathematics and Science teachers, each pair from the same secondary school. Our aim was to co-design software[2] about risk and about the teaching and learning of risk. We intended that the emerging software would act as a window on the teachers' thinking-in-change (Noss and Hoyles, 1996) by perturbing, making explicit and sharing ideas with each other and with the researchers in what was essentially a design research approach (Cobb et al,

[1] The funding of the Wellcome Trust is gratefully acknowledged (WT084895MA). Project website: www.RISKatIOE.org.

[2] The prototype was developed in Imagine Logo, an object-oriented parallel-processing version of Logo that allows the programmer many interface design options. It is published by Logotron: http://ns.logotron.co.uk/imagine/

2003). It is not our intention in this paper to present data from the teachers' activity but instead to reflect on the rationale for the design of the emergent software.

Deborah's Dilemma

The design research approach has so far resulted in software called Deborah's Dilemma. In this section, we set out a plain description of the software, leaving the explanation of the rationale for that design, based as it is on our interactions with the teachers, to the later sections of the paper. The reader might enjoy trying to anticipate the design rationale as they read this account.

Setting the scenario

We propose an imagined scenario in which a young woman, Deborah, suffers from a chronic back condition. There is available an operation, which might cure the problem or give rise to further complications, some of which might be regarded as relatively trivial and others, such as paralysis, that threaten Deborah's future quality of life. The teacher is challenged to judge how they would react in Deborah's situation and how they would advise Deborah.

A good deal of information is available, either through text or through talking-head videos, about the situation. For example, in describing the impact of the condition on her sporting activity, Debora explains: "I used to practice several sports which I can no longer pursue due to the stresses they put on my back. I am an adventurous person and enjoy kayaking, I have even tried hang-gliding. I like jogging but it is a high impact sport, which can jolt the vertebrae and cause even more damage. Gentle exercise such as swimming, yoga and Pilates actually helps to reduce the pain. Muscle-strengthening exercises help to keep the pain at a tolerable level." Similar descriptions are given about the medical condition and how it affects her working life.

Substantial information is also given about the operation that could be carried out. Deborah in fact is described as having three separate consultations and conducting personal research on the internet. This information yields different views about the likelihood of success and the possible complications that might happen. The teacher is expected to resolve these discrepancies and contradictions in discussion with other teachers.

The information about the condition can be used to model possible consequences of having the operation. The information about Deborah's attitudes and life-style can be used to model consequences of not having the operation. The modelling tools that are used in each case are described below.

Modelling the consequences of having the operation

The teacher is challenged to model the consequences of having the operation. Figure 1 illustrates the tool used to respond to this challenge. In Figure 1, the teachers have used the slider in the top left hand corner to set an overall probability of success for the operation of 0.7. They have used the 'Add Complication' button to include nerve damage, paralysis and superbug infection as three possible complications. In each case, they have used the corresponding sliders to set likelihoods for these complications. These likelihoods are overall probabilities and so cannot occur more often than failed operations. Two or more complications can occur in the same operation. Successful operations have no complications.

Towards the top of the Figure 1 the teachers have edited the number of times the simulation is run to 1000. We think of this as 1000 futures for Deborah. The results can be shown as a bar chart though we think the representation shown is more informative. The chart is colour-coded so that successful operation are shown in green, unsuccessful ones in red, and operations that are unsuccessful but have complications in stripes according to the range of complications. This representation enables the teachers to eyeball the whole set of Deborah's futures and gain a proportional sense of the various possible outcomes. The teachers might instead prefer to run the simulation once on the basis that Deborah has only one life and therefore we provide a 'run once' button towards the top of Figure 1.

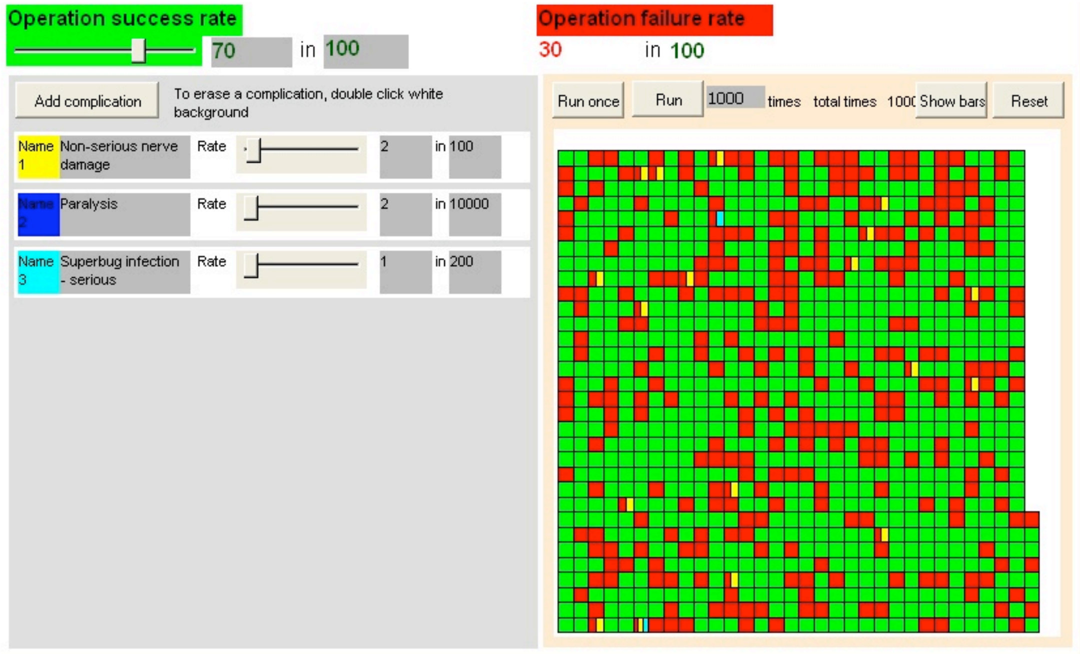

Figure 1: Two teachers model the consequences of having the operation

Modelling the consequences of not having the operation

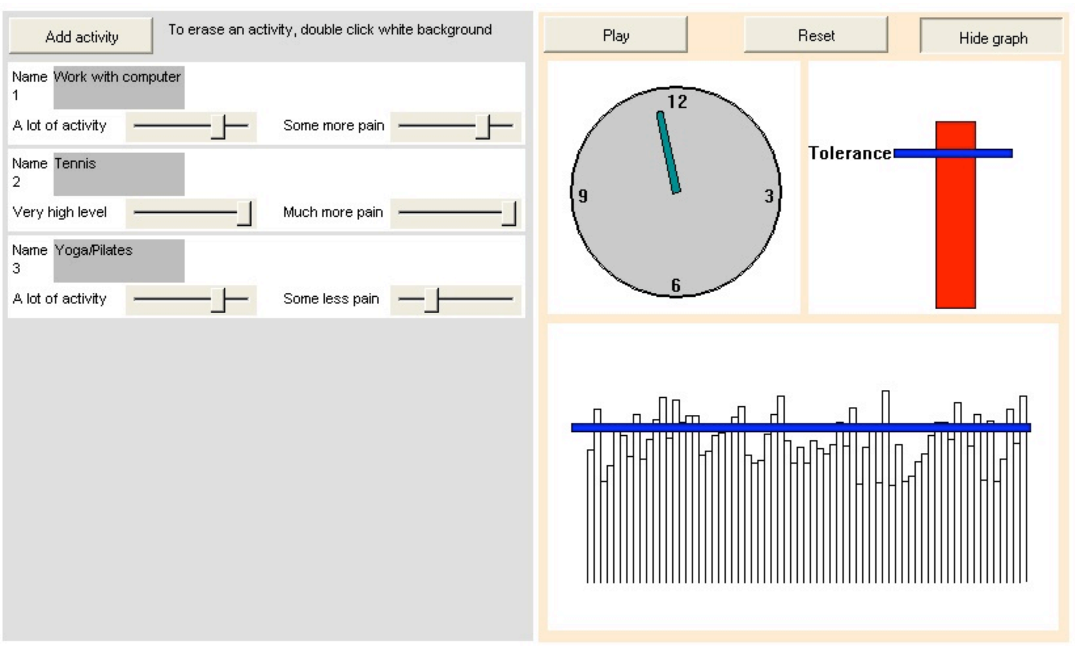

Figure 2: Two teachers model the consequences of not having the operation

The teacher is challenged to model Deborah's lifestyle. Figure 2 illustrates the tool used to respond to this challenge. In that, the teachers have used the 'Add Activity' button to include computer work, tennis and yoga as three aspects in a model of her life-style. In each case, they have judged how much of the activity is or might done by her and how much pain the activity might cause. When the 'Play' button at the top of the screen is pressed, the clock rotates and the red bar (the *painometer*) oscillates, indicating in time how much pain she is suffering. Teachers can set the level of tolerance they think is appropriate. The graph shows a trace of the pain level.

Comparing risks

Throughout the process of modelling the consequences of having or not having the operation, the teachers have been encouraged to keep a map of what they see as the possible resulting hazards. In Figure 3, two teachers have built up such a map using the 'Add Hazard' button, and entering information such as likelihoods, impacts or other perhaps value-based information.

When the teachers press the 'Show Risk' button in the bottom right hand corner of Figure 3, the boxes will change colour. Boxes towards the left of the screen will become darker while those to right will become lighter on a continuous scale. The teachers will be told that hazards with darker colours have higher risks and those with lighter colours have lower risks. Inevitably, the teachers will now judge that some of the boxes are in the wrong position on the screen. They are able to drag the boxes to what they judge to be the correct relative position according to their risks. In doing so, they will of course refer to their judgements about impact, likelihood and other information as entered by them into the boxes.

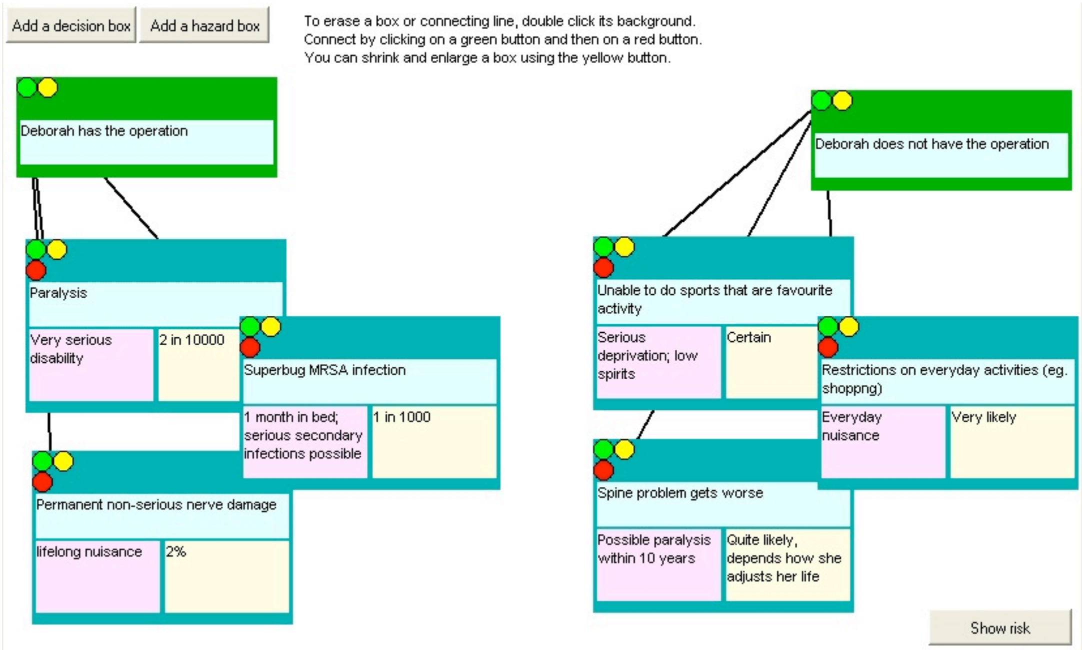

Figure 3: Two teachers map out key information before exploring the size of the relative risks

Design rationale

In the previous section, the software has been described in some detail. This section will now reflect on how the design decisions have been influenced by the need to develop pedagogical principles around knowledge that is not only uncertain but also contested.

Decision-making in complex scenarios

Our aim was to use the process of designing software to gain access to the teachers' knowledge about risk including its teaching and learning. We were though forewarned by the literature, as described above, about the deep sensitivity of knowledge about risk to context and it seemed that our aim of probing teachers' knowledge of risk would be undermined by an approach that separated the tool from a problem context. Indeed, we took the opposite view in which we intentionally embraced context.

Since risk is a tool that can be used in many decision-making contexts, it seemed appropriate to create a situation that was sufficiently life-like to provoke intuitive ideas that the teachers might bring to bear consciously or unconsciously in making such decisions. Pratt (1998) has referred to the use of context to stimulate relatively natural intuitions as *surface familiarity.* The attraction of such an approach to us as researchers was that the teachers might engage deeply with the scenario and that their activity might be driven by a sense of purpose and curiosity rather than by what they perceived to be the needs of the researchers. Our aspiration was that teachers' long-term commitment would facilitate the observation of teachers' utilities for risk (Ainley et al, 2006); in other words, we expected to identify how teachers thought risk might be used to make sense of such a scenario.

In fact, the real value of risk seems to be in supporting judgements in those contexts. We wanted to understand the nature of teachers' judgements. We therefore took the design decision to develop a complex scenario, which called for difficult judgement in the face of uncertainty and ambiguity. The scenario we developed sets up tensions between consideration of severe complications in the operation, such as paralysis, with low likelihoods of occurring, and life-style compromises that might be unacceptably debilitating, such as giving up work or sport. We tried to provide ambiguous and sometimes contradictory data, such as the conflicting opinions of various doctors and consultants and the outcomes from personal research on the internet about the types of complications that could occur and their likelihoods.

We have some limitations. In tying the exploration to one particular scenario, we are only able to observe the teachers' expressions as they relate to that particular situation, but nevertheless, we designed with the teachers software that:

1. Addressed a scenario with surface familiarity in order to expose an intuitive layer of knowledge about risk;
2. Was sufficiently complex that teachers would need to exercise judgement, exposing the nature of their thinking;
3. Incorporated ambiguous and conflicting information that would throw light on how the teachers weighed such evidence.

Making personal models explicit and computational

As designers, we faced our own dilemma. We described at the beginning of this paper the metaphor of planting nuggets of mathematical knowledge in the microworld with the intention that the user of the microworld would stumble across those nuggets. We noted the literature's ambiguous position on the nature of risk and pondered the design approach when there were no well-defined non-contradictory nuggets to plant.

We came to the view that the role of the software should be to expose what the teachers' imagined to be the nature of risk, what we refer to here as their personal models of risk. It became clear that our approach should emphasise expressions of risk as teachers interpret the scenario. However, the models that might be expressed by teachers could easily remain at a descriptive level. We aimed to push the teachers towards developing computational models that could be executed to generate feedback. Computational models require a level of explicitness, precision and unambiguity that is often not achieved by descriptive models that can be left unchallenged in their vagueness. We expected that feedback available from executing personal models might lead the teachers to re-evaluate their own thinking about risk. We also expected that by creating models, their ideas would be exposed to evaluation by colleagues, whose own models might also have a perturbing effect.

Thus, Deborah's Dilemma contains tools to express personal models about the operation and its consequences. These are expressed through the creation of complications. Which complication to include in the model is for the teacher to decide. Each complication can be given likelihoods of occurrence. What level of likelihood is for the teacher to decide. The model can be run as many times as is felt necessary by the teacher. Similarly, Deborah's Dilemma contains tools to express personal models about the consequences of not having the operation. These are expressed through the creation of activities. Each activity can be given levels of how much activity Deborah might do and how much pain is caused. Teachers make judgments about all of these factors. The model can be run to observe the fluctuating nature of Deborah's pain resulting from those life-style decisions.

Inevitably the modelling tools we provided shaped and constrained the teachers' expressions of risk, but nevertheless, we designed with the teachers software that:

4. Included tools to facilitate the expression of personal model of risk;
5. Provided feedback on the consequences of a personal model by making the models computational rather than only descriptive;
6. Encouraged sharing of personal models by making them explicit and open to scrutiny.

Fuzzy quantification

A particular aspect of making personal models explicit and computational was quantification. It was clear that risk should at least incorporate dimensions of likelihood and impact but how should we encourage their quantification without imposing a particular model of risk?

One unlikely but possible complication of Deborah's operation was death as an unfortunate effect of the anaesthesia. Many teachers might regard death as the most severe of possible consequences and look to set a very large, even infinite, value for its impact. An infinite impact could really only be offset by an infinitesimal likelihood, a mathematically untenable situation.

We also observed in working with the teachers a good deal of discomfort in trying to set specific values on impact. Since we were committed to the idea of the teachers creating computational models, we decided to deploy techniques, which we have labelled *fuzzy quantification*. This approach is most evident when modelling Deborah's life-style. Sliders are available to indicate how often Deborah might engage in any particular activity and what the impact on pain level might be. Categories like 'much more pain' and 'less pain' serve the purpose of fuzzy quantification. Pain itself is a vague notion, which it is claimed cannot be quantified in an objective manner as each person experiences pain in their own idiosyncratic manner. Nevertheless, we incorporated the notion of a painometer as a fluctuating bar with no specific scale and tolerance as a moveable threshold on how much pain Deborah could manage in order to partially quantify the consequences of the decisions made in modelling Deborah's life.

In short, we designed with the teachers software that:

7. Enabled personal models to be computational through fuzzy quantification of impacts;
8. Encouraged simultaneous consideration of impacts and likelihoods through fuzzy quantification of impacts;
9. Facilitated an appreciation of the consequence of a particular personal model of Deborah's life-style by the invention of a non-standard fuzzily quantified representations of pain and tolerance.

Facilitating co-ordination of dimensions of risk

Since risk contains at least the dimensions of impact and likelihood, it seemed important to consider both and at times to trade-off severity of impact against likelihood of occurrence. As we worked with the teachers, it became increasingly transparent that they struggled with attending simultaneously to likelihoods and impacts. For example, there was a tendency for them to come to one recommendation for Deborah when considering the low likelihoods of complications and another when considering the high impacts of some of those complications. We therefore needed to devise tools that might support the co-ordination of the various dimensions of risk without imposing a particular model of risk. The intention was not to lead the teachers towards a particular view of the nature of risk but to explore whether it was possible to devise tools that might enable risk to be seen as a single entity so that different hazards might be compared.

The mapping tool (Figure 3) was a late development in the software. Because there is a very large amount of information that described Deborah, her life, her condition and the operation, it was felt appropriate to provide a tool that the teachers could use simply to record what they regarded as key information. The provision of decision boxes, hazard boxes and connecting lines enables the teachers to structure that information. The innovation lays in the further provision of the risk button that colours the boxes according to level of risk, which can be altered by moving the boxes around the screen. The teachers' co-ordination of the dimensions of risk, as summarised in their notes within each box, is challenged and exposed by their actions and discussion stimulated by the need to move the boxes to an acceptable level of risk when compared to the other boxes. We observed how this activity threw up explicit mention of the need to balance impact and likelihood without the need for formal quantification such as when multiplying probability and impact. We believe that this concept-mapping tool is a first instantiation of a tool that supports the co-ordination of the dimensions of risk but we look forward to finding different solutions in the future. In short, we designed with the teachers software that:

10. Provided a tool for the co-ordination of the dimensions of risk through the fuzzy quantification of risk when comparing different hazards.

Conclusion

Although we have discussed the difficulty of designing a microworld when the focal knowledge is not only highly subjective but also contested by experts, we have been able to exploit the idea that one purpose of a microworld is to provide a window on activity for the users and for the researchers. In so doing, we are aware of various ways in which the Constructionist literature has informed the design process that has been summarised in the preceding section in the form of ten design outcomes.

The decision to construct a complex scenario was largely based on the need to offer a purposeful task that could lead to the exposure of utilities for risk. It is well established in the Constructionist literature that technology can afford a design process of phenomenalisation (Pratt et al, 2006) in which mathematical or scientific ideas become quasi-concrete objects (Turkle & Papert, 1991), capable of on-screen manipulation in ways that parallel the exploration of material objects in the lived-in world. The development of Deborah's Dilemma has involved the creation of on-screen instantiations of constructs of probability and impact in the form of sliders and risk as the colour of moveable hazard boxes. By utilising these quasi-concrete objects, the teachers grappled with Debora's Dilemma and exposed new understandings of risk. We see here Papert's Power Principle (1996) at work in the sense that the teachers were using risk even as their knowledge about risk was being transformed. Indeed, in developing the risk button in the mapping tool, we exploited the design heuristic that a window on a mathematical or scientific construct can be built by making a representation of the key idea, risk in this case, a central control over activity (Pratt et al, 2006).

The modelling that the teachers conducted in working with Deborah's Dilemma was primarily about expressing their own ideas for wider scrutiny. This contrasts to some extent with the common use of microworlds that embeds the mathematical or scientific idea for it to be explored. Although it is true that in Deborah's Dilemma, the notion of risk is phenomenalised, it is not unambiguously defined. The defining process that sensitises the teachers to the various dimensions of risk is more attuned to expressive modelling than exploratory modelling (see Doerr & Pratt, 2008) and we see this as a key consequence of designing a microworld where the key knowledge is contested. Papert makes a distinction between the nature of knowledge and the nature of knowing arguing that the first is a technical matter that belongs to educational school course and the second is epistemological. In exploring risk, it seems that both the nature of knowledge (contested and not tightly defined) and the nature of knowing are under scrutiny.

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