# 15 DEVELOPING A PEDAGOGY OF RISK IN SOCIO-SCIENTIFIC ISSUES

Ralph Levinson, Phillip Kent, David Pratt, Ramesh Kapadia and Cristina Yogui
Institute of Education, University of London (London – United Kingdom)
**r.levinson@ioe.ac.uk**

## Abstract

The aim of this research is to develop principles for a pedagogy of risk in socio-scientific issues. Risk is challenging to teach because of its contested conceptual basis incorporating epistemic and non-epistemic values, its situated nature and its mathematical basis in probability and statistics. In our project—Promoting Teachers' Understanding of Risk in Socio-scientific Issues (TURS)—we have built a set of mature software tools designed through an epistemological analysis of risk and consideration of teaching and learning, as reflected in discussions with teachers. This software provides teachers with tools that enable them to express what they see as the significant issues, giving feedback for them to redraft their models in light of the consequences of their decisions. Pairs of science and mathematics teachers modelled a scenario based on personal decision-making for a surgical intervention.
Inductive analysis of teacher dialogue generated four key findings: teaching risk lends itself to a multidisciplinary approach; recognition of the multidimensional nature of risk can be elicited through engagement with contextualised biological dilemmas; use of executable models promotes discussion of the complexity of risk, and expressive tools can be designed which support coordinated analysis of the multidimensional nature of risk.

**Keywords**: risk; socio-scientific issues; modelling; pedagogy; decision-making

## 1. Introduction

The importance of understanding risk in terms of public engagement with science and in critical support of science policy is summarised in the House of Lords Science & Technology report on Science and Society (House of Lords, 2000, Para 4.2): 'When science and society cross swords, it is often over the question of risk…'. Socio-scientific issues, such as those that arise in the media, can only be rationalised through an appreciation of risk as a multidimensional organising idea incorporating epistemological, psychological, sociological and cultural, and pedagogical perspectives.

The concept of risk commonly used today in the context of science and technology has its roots in the theory of decision-making, in the form of the 'subjective expected utility' (SEU) model: for every hazardous event there is both a likelihood of that event happening, and a numerical utility (also called dis-utility) measure which expresses the impact that the hazard would have on an individual or organisation involved should it occur (Edwards & Tversky, 1967). The arithmetical product of the likelihood and utility is defined as the 'risk' of the

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event. Hazardous events usually consist of many different interconnected hazards, and so there exists a 'total risk' for an event which is the sum of all individual risks. The SEU model then supposes that for someone faced with a hazardous situation, they can identify a comprehensive set of different possible courses of action, analyse those into sets of hazard events, give values for the likelihood and dis-utility of every hazard, compute the total risk of each course of action, and conclude with an optimal decision by selecting the course of action with minimum 'total risk'.

In contemporary technological societies, such a characterisation of risk is limited; there is debate on how risk is conceptualised (Wilensky, 1997): traditionally as the product of probability and impact around a particular event, but these variables are themselves subject to conditions of trust (O'Neill, 2002) and interpretations of lay and expert rationalities and context (Stilgoe, 2007). The psychological aspect arises from subjectivities and perceptions associated with risk (people are often willing to accept high risks with a low element of dread or a high element of familiarity, such as car accidents, but not low risks with a high element of dread such as airline accidents (Slovic, Flynn, & Layman, 1991)). In the sociological aspect, risk is seen in the context of institutional and cultural contexts (Douglas & Wildavsky, 1983), including the type of socio-political relations which make some risks either acceptable or unacceptable, for example, the use of vaccinations for the Human Papilloma Virus. The pedagogic aspect relates to the skills and confidence essential for teaching risk in the context of socio-scientific issues (Levinson & Turner, 2001; Ratcliffe & Grace, 2003).

Risk in issues in biology include the privatisation of genetic testing kits in which the healthy have now become the genetically unwell (Bennett, 2006) thereby imposing an artificial strain on health services, the causes of heart disease, screening practices, uncertainty about the epidemiology of cancer from new technologies such as mobile phone use and the emissions from base stations, and the international multi-party debate about risk and action on climate change.

Notwithstanding the global socio-political discourse on risk in science and technology, it has only recently begun to be incorporated into science curricula, most notably in England in Twenty First Century Science (Millar, 2006) and in Science in Society A2 level (www.scienceinsocietyadvanced.org). Despite an increasing emphasis on teaching risk, there is very little empirical research on its pedagogy. In this research project, funded by The Wellcome Trust’s Society Awards research programme, we start from the assumption that risk is multidimensional and interdisciplinary, involving ideas which span a range of domains including science and mathematics. In so doing, two factors underlie the research design:

- To perturb teachers’ thinking to gain a window on their thinking-in-change about risk and its pedagogy
- To embed conjectures about pedagogy into new tool designs.

Our research question, therefore, is twofold: To what extent can teachers' thinking-in-change about risk be captured through a structured microworld based on a utility approach? What are the implications for the design of new tools?

## 2. Methodology

### 2.1 Tool design and participants

We built a set of mature software tools designed through an analysis of the epistemology and the teaching and learning of risk, as reflected through research and in discussions with teachers of science and mathematics. These software tools embody emergent design ideas: the need to (i) involve the teachers in complex decision-making scenarios which draw on interdisciplinary knowledge; (ii) provide them with expressive tools to capture significant factors in decision-making; and (iii) provide feedback on the consequences of decisions made to enable redrafting of their models. By interacting more deeply with interdisciplinary knowledge, the aim is that mathematics and science teachers can be empowered to develop meaningful activities around the concept of risk. A key component of the research was that three pairs of teachers (one mathematics, one science) from the same school work together to explore the possibilities of cross-curricular working in their school, and become involved with the design work of the project.

### 2.2 Scenario

This research reports on findings from the personal decision-making scenario called ‘Deborah’s Dilemma’ (accessed at www.riskatioe.org) in which teachers input probabilities for the success and side effects of a surgical intervention based on their interpretations of advice given by various medical authorities, and taking into consideration the possible consequences based on Deborah’s lifestyle.

Teachers are invited to put themselves in the position of a fictitious person, Deborah, on whether to have an operation that could cure a spinal condition that is causing her considerable pain. The operation would entail certain hazards with risks that need to be inferred from various authentic sources of information, such as doctors, back pain specialists, internet searches, and anecdotes from patients who have had surgery or who are considering having surgery. There is also a short presentation with pictures and cross-sections of lumbar intervertebral discs to identify the regions and procedures for intervention. Ambiguities in the data are deliberately set up in order to provoke discussion and debate; for example a “spine expert in London” and “a surgeon in a regional hospital”, give conflicting opinions—who should one trust? Choosing not to have the operation would entail a lifestyle choice to manage the ongoing pain resulting from the spinal condition. Two software tools accompany the information about the condition. The first (“Operation Outcomes”) is a probability simulator in which users model the possible consequences of having the operation (Figure 1). Numbers of operations can be varied so participants can look at the probability of success/failure for just one operation or, for example, for a million operations. The likelihoods for various complications (i.e. side effects of the surgery, ranging from minor to serious, such as superbug infection, or death through general anaesthetic) are represented on the simulator once teachers have inputted a range of probabilities related to outcomes and side effects.
The second tool, the “Painometer”, attempts to give a rough estimate of Deborah's pain and how different activities may cause it to increase or decrease, relative to a “tolerable” level. Pain defies objective measurement; hence the personal perception of pain is a potentially interesting but problematic context for probing people's personal models of risk. Users are required to decide what everyday and leisure activities Deborah should or should not do if they were in her position, and in what amounts, and to infer from the information the effect of those activities on Deborah’s pain level (as expressed through the dynamically varying height of a vertical bar as a “painometer”). The intention is for the tools to promote quantification of risk in a real context, allowing for personal interpretation, while not being constrained by formal models of risk such as exist in statistical decision theory, and which are conventionally used in risk assessment.


**Figure 1. The probability simulator.**

### 2.3 Data collection

The three pairs of teachers (one science and one mathematics practitioner from the same school in each pair) worked through Deborah's Dilemma to arrive at a specific decision about what to recommend to Deborah. A researcher sat with each group but only intervened to demonstrate relevant aspects of the software, to address any technical points and to ask questions for clarification. Having arrived at a decision, each pair of teachers wrote a report explaining their reasoning. Video screen capture software recorded the process of inference-making through the teachers' dialogues and manipulation of the simulators. The session lasted approximately 2 hours.

Data for the analysis consisted of an audio transcript for each pair of teachers, a video record of their interactions with the software, their written account of the reasoning behind their final decision, and notes from each researcher, including observations from a 'floating' researcher who was able to compare the inference-making of each pair.

## 3. Results

The following points emerged from thematic analysis and inductive coding of the data. The pairs of teachers responded to the data and Deborah's storyline in the following ways.

### 3.1 Analysis of the statistical data favoured having the operation

After creating models with probabilities (see Figure 1), the teachers concluded that the operation was safe, i.e. low risk, with failures being relatively rare and complications even more so. They tended to agree that it was worthwhile having the operation. The following extract is part of a discussion between Tim (a mathematics teacher) and Nathan (a science teacher) as to what action they would take based on the statistical data.

Episode 1

N: So really, the complications that are likely to happen aren't really going to be a problem. She might feel a bit rough.

T: Yeah.

N: The trachea and the nerve roots are possibly serious.

T: Yeah they could leave her worse than what she was in the first place.

N: In our simulation that was four out of 51 wasn't it?

T: What—four out of 1000 operations?

N: Four out of 1000.

T: Out of the failures it was four out of 51. But you've got 51 failures which means 47 operations just didn't work, it just didn't do what it was supposed to do. And out of those four there were possibly serious complications, so that's, you know, point less than half of a seventh.

N: We've got to decide if we write that. If we're recommending the surgery then we'll write that, and if we're not recommending the surgery then we'll say four people (laughs)…

N: I think I'm for having the operation actually. Personally I was always for having the operation. I don't know, nothing there has made me change my mind.

T: At the moment we're having about half a percent big problems, and it looks like the failure rate is about what you'd expect, so I think anybody…oh sorry five percent failure rate…so out of those five percent there's only about half a percent overall and out of the failures only about 10% of the failures could be quite serious. Overall it's only a half percent that could be serious problems; I presume the other failures would just be called a failure that doesn't cause you any problems. That's what I'm thinking, that's my perception of it.

All three pairs of teachers supported having the operation based upon modelling the statistical data. However, there were a number of mediating factors. First, the teachers frequently referred to personal experiences of either being in hospital or having operations. Secondly, they questioned the provenance of the data: they wanted, for example, to know how many operations the back surgeon had carried out; if the quoted figures were for the UK only, for certain regions, or for other countries. The source of the data was always important to them, and occasionally the amount of data. In the face of uncertainty, the teachers saw the data from the most authoritative source as being the most reliable. Thirdly, they occasionally came across problems in translating the data from one form to another, as emerges from the dialogue between Tim and Nathan and, for example, between Linda (a biology teacher) and Adrian (a mathematics teacher).

Episode 2

*[The surgical operation]*

L: It must be pretty bad pain to consider…

A: If you're going to consider the surgery it's got to be.

A: 'Unwanted after effects' (laughs). So 95 to 98% successful. So that's…is that 95 to 98% of the time the pain is relieved? Or 95 to 98% of the time there are no complications?

L: That's a good question.

...

L: Complication three…oh ok so you don't need to…more risky than what's going on. 'This was helpful…I asked my doctor for a second consultation…' Yeah, major surgery; general anaesthetic is another risk, and the superbug.

A: 'Currently about 0.00025%', 25 in 100,000.

L: See that's what we were thinking; '…developing my lifestyle to support long term management of the pain'. '…Yes, I can live with the pain and I have adjusted my lifestyle successfully'. It's more of a lifestyle operation; it's not something that's going to save her life is it?

A: Well she'll still be alive but it's got implications right through doesn't it? I suppose if it does deteriorate you set yourself up for…

L: Well if anything did deteriorate you'd be in a different position but if you lived slightly different then…Do you want to look at the other two options?

A: One in 1000 for general anaesthetic.

L: That's one in 10,000.

A: One in 4000 for the superbug.

In lines 7-14, a probability of 0.00025% of contracting a superbug is mistranslated as 25 in 100,000, or 1 in 4000. In fact this is far too high for the current prevalence of superbug infections in UK hospitals. In paired dialogue, it was easy for teachers to miscalculate small figure percentage values into the more prevalent discourse and numbers of chance and probability. This illustrates a common problem in which people find large numbers and low probabilities very hard to comprehend and deal with. It reflects the need to take care in the design of materials about risk, possibly highlighting the need to support consumers in negotiating and interpreting the ways in which probabilities are represented.

### 3.2 Attention to the focus of the problem influenced teachers' decision-making in terms of risk

The shifting of position seemed to relate to where the teachers' attention was directed, often by affective reactions to the context of the scenario at any particular point in time. This resulted in fluctuating decision-making in the dialogue between the two teachers as reflected in this exchange between Linda and Adrian.

Episode 3

A: I'd have the operation, give it a go. That's my lifestyle.

L: If someone said you couldn't play football, that would be important? You wouldn't be prepared.

A: Not only that, it's self-sufficiency as well. You need someone to do your shopping for you, already at 38.

L: Well she can use a trolley.

A: No, she can't lift a shopping bag—doing shopping would make you worse. Everything you chose to do for yourself would make you worse, leading to a more serious condition.

L: If you're recommending it purely on the odds, right...

A: No, not purely, I'm recommending it possibly against the odds, you know 3... over here [looking at written notes] complications or failure is 5%.

L: If you were saying it for yourself, you would be prepared, but say you were making it for her—then you'd be saying, well actually.

A: Right, we have to come down on one side or the other, we can't just re-present the evidence, we've got to say 'we recommend you do this', we can't sit on the fence.

L: Do you think if you were the doctor, if you were someone close to Deborah...

A: You might have a different opinion.

L: ...it's going to come down to the relationship with the patient as well. What are we, we're just people looking at statistics, if the computer says no, because at the moment to me the computer is saying no.

A: 3 in 1000 serious complications.

L: That's serious, you are 38 your life could—

A: Yeh!

L: Because the computer...[laughs] Who are we??

A: That's the question isn't it?

L: All these things, is lack of sleep, nausea, even depression…

A: That can ruin your life.

A key overall observation about Adrian and Linda's exploration is that there was a regular switching of positions which depended on the information immediately in front of them (the 'availability' heuristic), and their shifting estimations of impact. Initial exploration of the "outcomes" tool suggested a likelihood of serious complication arising from the surgery on the order of several cases in 1000, and they initially talked about this as a "reasonable risk". However as they explored with the Painometer tool, they began to favour a non-surgical approach and to reassess the reasonableness of the surgical risks. Our interpretation is that they were left in an ambiguous position between the two "sets of evidence" and in the end rationalised their position by appealing to the authority of the "specialist in London". Linda comments:

'I think the fact she's gone to the person who knows more about it, spends his life looking at risk, he says no there are better things out there for you, other options… As a scientist I would go with the specialist spine doctor who knows more about it, I would go with what he says'.

It would seem that Adrian (the mathematics teacher) brings in the probabilities to make the choice; this is mediated by Linda (the science teacher) who brings in social issues, stressing the impact (minor and major complications); Adrian changes his mind, as illustrated in the final recommendation that the pair produce, presented as a personal letter and reproduced below. It should be noted that this happened with just one pair of teachers and illustrates the importance of collaboration and discussion between teachers from (different) disciplines. Such subtle distinctions between science and mathematics teachers were observed in the other two groups as well. The approach taken by the project enabled effective cross-curricular working in an aspect of pedagogy which is often absent from classrooms, the discussion of issues beyond the quantitative or scientific evidence.

> '….We have looked at the probabilities of failure and complications during surgery and whilst the likelihood of severe complications is around 0.4%—possibly quite low—we are unsure as to the exact chance of success as the study quoted by your first doctor referred to arm pain only and we are inclined to take the opinion of the spine specialist that managing your condition is the best course of action.'

### 3.3 The problematic interactions of likelihood and impact

Standard risk theory involves a coordination of the likelihood of an event with its impact. That such a coordination is problematic and difficult to integrate can be seen from episode 3, in which Adrian and Linda have difficulty linking these two dimensions, not surprisingly given the complexity of the dilemma, its situated and affective nature. Impact is both difficult to quantify, even in relatively simple contexts, and to compare between contexts. To support teachers in coordinating these factors and rough estimations of risk, we designed a mapping tool which allows early reflections in linking likelihoods to impacts (Figure 2). This tool allows participants to combine likelihood with impact and arrange their estimates of risk across the screen. This tool was subsequently used with 14- and 15-year-old science students in a secondary school who were able to discuss these two factors together and compare risk situations across the screen.

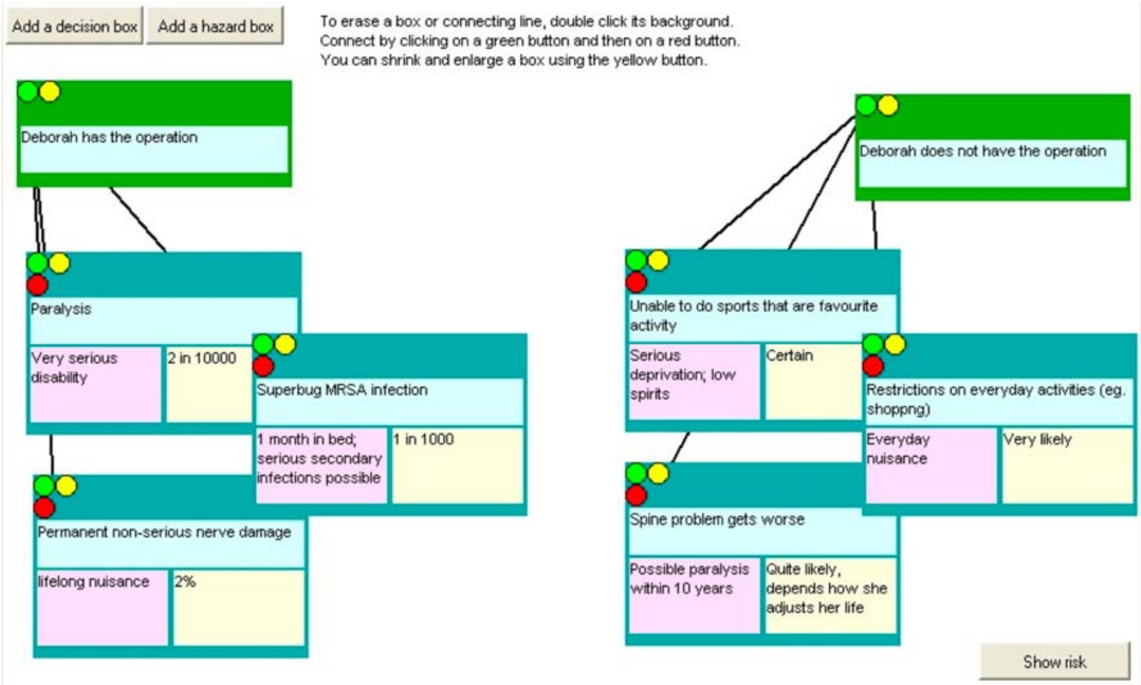


**Figure 2. The mapping tool.**

## 4. Conclusions

Section 3 presents only a snapshot of the diverse themes discussed by the pairs of teachers, but focuses on the commonalities between them. While teachers are able to draw informal inferences given sufficient knowledge of context (Pratt et al., 2010), empathic and affective responses mediate decision-making about risk, and executable models make the various dimensions of risk-taking explicit. From the evidence of teachers' interactions with a co-designed flexible model of a risk-taking scenario, we have devised four pedagogic theory components which incorporate our findings.

- Risk is a multidisciplinary subject that can be addressed within conventional school structures.
- Risk is multidimensional, embracing at least the elements of likelihood, impact and value-laden ethical considerations. Recognition of the various dimensions can be stimulated by engaging with specific contextualised socio-scientific dilemmas and discussing the multifaceted nature of the dilemma.
- A modelling approach that encourages making the dimensions of specific contextualised socio-scientific dilemmas explicit in executable models supports recognition of and discussion about those dimensions, as well as awareness of the consequences of their characterisation of the dilemma: building and evaluating computer-based models renders the knowledge captured by those models more open to reflection, discussion and evaluation (Hoyles & Noss, 1992).
- Expressive tools can be designed that support the coordination of the dimensions of risk.

## 5. Implications

Personally oriented executable models which include tools for dialogue around taking risks in scientific issues offer the possibilities of interdisciplinary planning to teaching about risk for tasks which are framed in specific decision-making contexts. Incorporating value components from personal and social heuristics demonstrates how quantification is mediated in decision-making. While expressive tools can be designed which coordinate the multidimensional aspects of risk, it is still not clear how these dimensions are coordinated. Nonetheless, these tools provide a potential starting point for research in other contexts, such as genetic testing and nanotechnology.

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