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SECTION II

TECHNOLOGY’S FAUSTIAN BARGAIN FOR EDUCATION
JOCELYN WISHART

VISUALLY DOMINANT, DYNAMIC AND YET DECEPTIVE

The Nature of Simulation Technology as Displayed in Secondary School Science Teaching

ABSTRACT

A review of teachers’ reports on their use of information and communications technology in science lessons by Rogers and Finlayson (2003) determined simulations to the most popular category of technology used in science education. Over 95% of science teachers reported that using computer-based simulations enabled them to achieve their teaching objectives, and their reports referred to simulations as stimulating thought and clarifying ideas, an efficient use of time, and motivating for students. Newton and Rogers (2003) note that potential benefits to student learning (such as clearer understanding and thinking) arise in science lessons when teachers exploit intrinsic properties of the simulation software, such as their speed in processing large quantities of data and dynamic display or animation of changes. However, using simulations effectively is not as straightforward a task as it first seems.

The study reported in this chapter investigated five teachers’ planning decisions for deploying computer simulations in science lessons and how their decisions appeared to relate to the intrinsic properties of the simulation software. The five study participants, all experienced secondary science teachers, volunteered to take part in the Interactive Education Project administered from 2001 to 2004 by the Graduate School of Education at the University of Bristol as part of the ESRC-funded Teaching & Learning Research Programme.

Analysis of the teachers’ decision-making and thinking indicates that each teacher made the necessary pedagogic shift suggested by Barton (1998), rethinking rather than replacing their teaching with technology. In moving beyond their original perspective that simulation was an impoverished version of practical work, teachers’ reflections on the intrinsic properties of simulation software:

• shed new light on planning various teaching strategies for using simulations in school science (e.g. deploying simulations after teaching a topic to consolidate understanding, encouraging students to explore and control the computer, and having students critically to review the model used in the simulation software);
• highlight issues concerning the moment-by-moment direction, locus of control and focus of student learning; and
• confirmed previous research (reviewed by Osborne and Hennessy, 2003) that student exploration and control, dynamic visual representation and freedom from laborious processes are the most salient features linked to successful simulation use.

Most importantly, this study alerts teachers excited by the visual power of simulations to plan their use carefully. Some widely available simulations are scientifically inaccurate and many multimedia representations simplify the targeted science concepts. Teachers should seriously consider what is gained and what is lost in exchanging authentic ‘messy’ science activities with sanitized computer simulations.

INTRODUCTION

Rogers and Finlayson (2003), reviewing science teachers’ self-reported use of Information and Communications Technology (ICT) in lessons, learned that simulations were the most popular category of software. Over 95% of teachers reported that using simulations enabled them to achieve their teaching objectives, and their reports referred to simulations stimulating thought and clarifying ideas as well as being an efficient use of time and motivating.

Owen (2002) points out that two groups of simulations exist, those that are praised for their potential to extend the scope of science school experiences allowing students to access phenomena that would be too dangerous or expensive, and those that are purposely designed to be more explanatory so students are engaged in abstractions that would otherwise be too difficult or unavailable. For example:

“In real life one cannot see the particles emitted from a radioactive source that are detected by a Geiger-Counter. A simulation of a ripple tank can allow the teacher to discuss observations with students in a controlled and predictable way.” [Owen, 2002, p1]

However, educators need to look beyond the visually exciting and attractive graphics and animation to the way simulations are deployed within the science lesson. The UK Office for Standards in Education (Ofsted, 2001, p12) complained that too many teachers “select software packages for their visual appeal rather than their relevance to lessons”. For example, they noted a primary science lesson being dominated by students’ passive viewing of a simulation of materials dissolving.

Effectively using computer simulations is not as straightforward a task as it first seems. For instance, Baggott la Velle, McFarlane and Brawn (2003) describe the complex and interrelated processes of subject, pedagogical, pupil, technological, curricular and contextual knowledge transformations that a science teacher must make in order to teach successfully through simulation software. Wellington (2000) cites several concerns inherent in science simulations. For example, computer
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Simulations are idealized versions of reality built upon invisible, unquestionable, and often simplified models of a scientific process that give the students the impression that every variable is easily controlled.

However, if what may be gained and lost in using computer simulations is made evident in planning science lessons, then the potential positive outcomes of using simulation software may be realized while mitigating what may be lost. Osborne and Hennessy (2003) consider this potential to lie in six key areas. The first is in increasing the scope of reference and experience for the student through exploiting the power of visual representations to develop understanding—particularly of abstract phenomena like electricity flow. The second is in supporting exploration and experimentation through providing an immediate link between an activity and its results increasing the likelihood that students will relate the visual representation of relationships to the activity itself. This not only provides immediate opportunities for study but can also encourage students to pose exploratory (“what if...”) questions and to pursue these by conducting follow up activities. This leads immediately to a third area of potential—structuring and supporting active engagement in learning. Genuinely interactive software requires active learner contribution and engagement (i.e. an element of reflection on choices and their effects), and this may include prediction, trial and evaluation (Rogers, 2004). Fourth, interactive computer simulations have potential to expedite and enhance work production, releasing students from laborious processes such as setting up equipment and recording results. For example, students often have great difficulty in successfully constructing electrical circuits which are known to give rise to problems in identifying and locating faults. Osborne and Hennessy (2003) describe simulations as yielding less ‘messy’ data and illustrating phenomena without the ‘noise’ of unwanted variables and human error in measurement. A fifth related area of potential is the way simulations enable students to focus on overarching issues by increasing the salience of underlying features of situations and abstract concepts such as current and voltage in electrical circuits; helping students to access ideas more quickly and easily, to formulate new ideas and transfer them between contexts. Finally, related to all of the above are the well documented motivational effects of using ICT, which seems to be intrinsically more interesting and exciting to pupils than using other resources (Denning, 1997, Cox 1997). In particular, improved motivation and engagement can be seen in students when using tools such as simulations and games which permit active engagement and offer pupils a degree of control over their own learning (Wishart, 1990).

Many of the researchers cited in this paper (Rogers and Finlayson, 2003, Baggott la Velle, McFarlane and Brawn, 2003, Wellington, 2000, Newton and Rogers, 2003) agree that for students to directly benefit from the multi-faceted potential of simulation software to enhance teaching and learning, the science teacher must carefully consider their planned use of this technology.

Newton and Rogers (2003) describe simulations and other ICT tools as adding value to science lessons through: (a) the intrinsic properties of the software such as the speed it can process large quantities of data and the way it can display or animate...
changes, and (b) potential student learning benefits that derive from the mode of application of the software such as clearer understanding and thinking. These are broad claims, and students may well not understand what it is that the technology is making easier for them, thus clouding the targeted science concepts. Again, if potential learning benefits are to be realized, issues such as these must be addressed beforehand when deciding whether and how to use a simulation. In this planning the teacher needs to bear in mind the possible Faustian bargains, for instance, that students may develop one set of ideas they attach to the simulations and another set of ideas they attach to the real world or that students may gain knowledge of a single scientific process at the expense of a wider understanding of the complex nature of science as found in the real world.

The study reported here investigated five experienced science teachers’ planning regarding incorporating simulation software and what they saw as the intrinsic properties of simulations that enhance learning.

METHOD

The five study participants took part in the Interactive Education Project (http://www.interactiveeducation.ac.uk/) run by the Graduate School of Education at the University of Bristol (Sutherland, Robertson and John, 2004). More than fifty teachers, including six science teachers, partnered with teacher educators and the researchers to create new ICT lesson designs for teaching. The project was predicated on two assumptions: (1) teachers are central to learning in school, despite prior ICT pedagogical research underemphasized their role (Sutherland & Balacheff, 1999); and (2) ICT should be incorporated into a designed learning situation as appropriate, with attention directed to the whole classroom context including classroom talk, work on paper and other technologies that are usually available to a teacher.

During the three year project the teachers worked in partnership with both teacher educators and the researchers and were interviewed and observed throughout the design, implementation and review of these new lessons. For the purposes of the project, the lesson designs were termed Subject Design Initiatives (SDIs) and were informed iteratively by theory, research-based evidence, teachers’ craft knowledge and the research team’s expertise. Reflecting Rogers and Finlayson’s (2003) findings, each science teacher chose to involve simulation software in their SDI.

Baggott la Velle, et al. (2004) have previously reported on the study participants’ views toward computer simulations in science teaching prior to implementing the SDIs. All the teachers were interested in the role of ICT in schooling, were supportive of its use in science, and had realistic expectations about its potential to enhance teaching and learning. They did, however, express that computer simulations presented an impoverished version of practical work and science inquiry. They did not appear to acknowledge the potential of simulation to mentally engage students in learning, or to build content knowledge and facilitate understanding through dynamic, visual representation. Baggott la Velle et al. (2004) speculated that the
subject culture in the UK, where the National Curriculum separates science inquiry from science content knowledge, contributed towards this perception.

Once the SDIs were under way each lesson was video recorded in its entirety and followed up by a semi-structured post-project interview lasting 60 to 105 minutes. The questions that framed these interviews addressed:

- teachers’ perceptions of the successes, problems and challenges of working with simulation software;
- changes, occurring during the project duration, in teachers’ approach to incorporating simulation software in their practice and how this related to student learning;
- teachers’ views about using simulation software in teaching, and how they changed during the project; and
- teachers’ views about other processes they experienced during the project (e.g. working in SDI teams).

Five of the original six science teachers were available for the post-project interview. The results of these semi-structured reflective interviews, conducted by a member of the Interactive Project team, appear in the next section.

FINDINGS

In all cases, simulations were planned to be used in hands-on mode by the students. The teachers, in particular Teacher A, considered that offering students a degree of control over learning activities, such as in choosing the parameters for each run of a simulation, can provide challenge, motivation and engagement. In answering the interviewer’s questions Teacher A compared the use of the Crocodile Physics electricity simulator (see http://www.crocodile-clips.com/crocodile/physics/ for a recent version) to making physical circuits using cells, switches, wires and bulbs with grade-7 (age 11–12 years) students.

He was delighted to find his lesson free from the usual barriers to students learning about the way electricity flows in circuits caused by problems with rusty connectors, broken wires, cells that quickly lose their charge and ‘blown’ bulbs.

“no matter how hard and how efficiently the kids work, they sometimes are dogged by just basic resistance problems in the circuit which are nothing to do with them.”

As part of his SDI he had measured improved learning amongst the students using the simulation:

“We did some tests before and after to see what they came to us knowing about basic circuit work and conduction and various things, and we did a test afterwards. Most improved considerably in their understanding of what was going on…..I think possibly it was even better than I expected because I was a
bit dubious about whether they were going to be able to cope with the concepts at that age.”

Teacher A noted that students could safely explore a greater range of options — including creating short circuits and ‘blowing’ bulbs — that would have been problematic in working with physical equipment. Because students could play around with the circuit components just to see what would happen, things they might be reprimanded for in class, teacher A noted students “felt that they were in control of their learning. They had this idea that they were able to use it for themselves. And that, to a certain extent, was the case. I allowed them to have a little play on occasions, particularly as extension work.” This view resonates with Wishart’s (1990) earlier observations of students using both educational computer games and simulations where the opportunity to choose the path through a simulation game was found to be closely related to the amount learned from it.

The discussions in the teacher interviews tended to corroborate the six key learning opportunities of simulations identified earlier in the introduction to this chapter. For example Teacher D (who chose to use a Web-based interactive simulation of a voltaic cell in her SDI) notes the problem of ensuring students observe the relevant changes in studying how a real voltaic cell works:

“For example with voltaic cells, sometimes when you put two different metals together and you’re trying to create a voltage the difference is so small that you can’t actually pick up that anything is happening at all. Or sometimes the reaction is over so quickly, that I thought if they could actually … if they could get their hands on the interactive software and do it over and over again
they could actually stop and start and use different combinations of metals and see what was going on in principle [...] that would be more of a sort of useful experience for them, rather than me sort of saying ‘Oh it does happen really, it does, you have to believe me on this.’”

Teacher D used simulations, such as that appearing in Figure 2 (see http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm), with grade-9 students (age 13–14 years). The teachers linked the student learning they perceived occurring with the power of animated visual representation, and their lessons were designed to capitalise on this. For example Teacher D provided the following justification for why she thought the voltaic cell simulation helped students learn:

“For me I think it’s visual, isn’t it? I mean like for example seeing the electrons actually moving, as opposed to thinking of electrons moving. […] I think that has more to do with learning. […] It’s all right saying the electrons [or ions] are there, but it’s another thing to actually see them doing what they should be doing, and sort of having the effect that they should be having.”

Simulation was also employed in order to release students from laborious (and often confusing) manual processes. Teacher A found Crocodile Physics useful because it allowed the students to interact directly with the concepts being modelled without
the interference to their thinking that too often arises from the poor connections
found in electrical circuits constructed in school.

Teacher J also noted a shift in his interaction with grade-10 (age 15 years)
students when he used simulation software (see Figure 3) with a standard school
laboratory practical investigating the effect of temperature on enzyme activity. He
reported that conducting the experiment with authentic materials requires him to
devote significant time to checking problems with laboratory equipment which
often supersede the teacher’s ‘intellectual input’. Once the computer simulation was
running he spent less time helping children to understand what the task was and more
time “discussing the learning points that the simulation was there to demonstrate”.
However, he did raise a concern about the predictability of the dataset that was
programmed into the simulation, and was pleased that a number of his more able
students realized this limitation of computer models:

“Of Set 1 probably about 4 or 5 [students] came up and said ‘This is no good
as coursework because we can’t vary anything. We’re varying things but we’re
all coming up with the same results.’ Brilliant. They’d actually seen the top
end limitation of the computer simulation… And in a way that’s more useful to
understand – that computers are limited.”

Teacher J’s experience highlighted the importance of the relationship between the
students’ ability and the way that the simulation software influenced their learning.
On reflection, he realized that he needed different teaching strategies for using the
simulation with his two student groups. With the less able group the power of the
simulation to increase their scope of experience through visual representation was
paramount. It also allowed them to repeat experiments as often as they needed in order to perceive patterns in the data, which could not be done practically in the time available. He noted: “You can generate far more data, and see the whole curve rather than four points on it”. However, with the more able group, he needed to go beyond the more salient points and relationships so nicely presented in the simulated experiment to plan a lesson that addressed the premises on which the model underlying the simulation was based.

In the above examples, the teachers were replacing a hands-on based lesson with a computer based simulation. Teacher B, however, used both with one group. Through doing so, he also spotted the learning opportunities offered through unpacking the simulation and considering the underlying model. He was teaching electrical circuits to a group of able grade ten students. After introducing the content with the usual accompanying hands-on activities he then used a CD-ROM based simulation called ‘Furry Elephants’ (see http://www.furryelephant.com/ for a recent version) (Figure 4) with the group in order to clarify the underlying theory of electricity as a flow of energy carrying charged particles.

However, some of the more able learners, prior to using the computer simulation that illustrated energy being dissipated at specific components, had already developed the accurate idea that energy is dissipated throughout a circuit. Teacher B learned from this experience to review the models used in many simulations carefully in developing a second SDI for older students. This second SDI focused on grade-12
(age 16–17 years) pre-university physics students using the Internet to research and review examples of photoelectric effect simulations.

Therefore, both of Teacher B’s SDIs included discussion regarding how the students’ understanding of the topic was actually in conflict with what was being represented in the simulation. Teacher B was particularly pleased with the students’ responses to the second SDI. He concluded that this was an effective way of using the simulation resources on the Web to reinforce learning, because it could circumvent the problems of incorrect science in the simplified models used:

“[Students] have to be critical. They’re being more active and proactive in their learning, rather then just reacting to what they’re seeing in front of them and automatically grabbing it off the Web because it looks pretty. They’re being critical. And teaching critical thinking has got to be a good way forward.”

Teacher B hit upon a method of planning for the use of simulations in science that might somewhat allay Wellington’s (2000) legitimate and important concerns about them being idealized and simplified models of reality. By immediately acknowledging that the models on the Internet were not all perfect and asking able students to review them in the light of how effective they were at illustrating the photoelectric effect, he encouraged students to reflect on and review their own understanding, thus reinforcing and consolidating the targeted concepts. Teacher B reported that:

“Following the SDI the year-12 students displayed a greater confidence in their use of scientific terminology associated with the photoelectric effect and had gained a deeper understanding of the concepts underpinning this.”

He considered that as an activity:

“It worked very well and I think the fact that they were able to do it in their own time was a better utilisation of time and didn’t have the associated problems with computers [in school].”

Teacher B also asked the students to compare the explanations provided by him, the textbook, and the Web. In this way they were encouraged to explore and check the scientific explanations from these various sources. In effect they were engaged in meaning-making activities that prompted them to contrast their own ideas developed from their earlier practical work with the scientific models presented in the computer simulation. Here the teacher promoted cognitive change by employing a strategy advocated by Doise and Mugny (1984) whereby group-generated conflict stimulates the joint construction of a more advanced concept. This strategy has also proved effective for teaching science concepts to younger secondary school children (Howe et al., 1991).

Teacher T had intended to use Multimedia Science School simulation software to investigate terminal velocity (Figure 5) with grade-9 (age 13–14 years). His most able students were experiencing difficulty grasping the relationship between terminal
velocity and the concept of balanced forces. For him, the significant advantage of this simulation was that it allowed a slower ‘investigation’ of terminal velocity than possible with standard school laboratory equipment. However, the experience did not go according to plan as the school had problems running the software over its network.

In responding to the interviewer’s questions based on his general experiences with simulation software, Teacher T noted that he prefers to use simulations for their ability to extend pupils’ thinking and consolidate their understanding rather than to replace practical work.

“The concept – do an experiment and then use the simulation to help kids think about what the … particles [are doing] would be the ideal example of this, wouldn’t it?”

“we clean up the experiment, get rid of all the messy worldliness of it, and then use that cleaning up process.”

This and other commonalities in the way science teachers perceived the use of simulation software to support teaching and learning in science are discussed in the next section.

DISCUSSION

When reflecting on the intrinsic properties of simulation that affect teaching and learning in secondary school science the teachers in this study fully supported the
range and variety of potentials reported by Hennessy and Osborne (2003). The five teachers were clearly seizing on several salient aspects of simulation software and attributing student learning to them. In Orwellian terms simulations are viewed by science teachers as ‘doubleplusgood’, especially for their visual animations with their power of multimodal explanation and making the invisible visible, a feature that is viewed as key to their pedagogical value.

Teachers A and T both emphasized the improved motivation and engagement of pupils when using simulations. Teacher A described his pupils as ‘switching into overdrive’ when using the computers. However, Teacher B noted that such engagement is less likely if the teacher operates the simulation themselves using a data projector to display the computer screen to the whole class. The latter is likely to lead to the scenario observed and criticized by Ofsted (2001) where teachers, impressed by the visual power and clarity of explanation in simulations, unthinkingly if not unknowingly, operate the software themselves and display the results to a physically and mentally passive audience.

Simulation software also has the potential to turn a misplaced connection (e.g. an overloaded circuit or an insufficient model) into a learning point. Teacher A noted that his students actively ‘blew’ their simulated light bulbs with glee and learned from the process. Teachers B and J both used student identified problems with their simulations to develop students’ knowledge and understanding. In one case the visual representation was at fault and in the other, the underpinning model was unexpectedly limited.

Teacher J and Teacher B found that, with forethought and planning, most simulations can be used to provide challenge for a wide range of groups, improving motivation and engagement of the pupils, clarifying and reinforcing their learning. Whilst they both chose to follow class practical or research tasks with simulation based activities to clarify and reinforce the underlying scientific principles, their pedagogical rationale for this order was not tested in this study. An interesting question worth pursuing in future work is whether students must have an initial conceptual understanding of the simulated phenomenon in order to get the most out of a simulation? If so, how is this initial conceptual understanding developed, and what is the role of tactile experience with authentic phenomena in developing that understanding? Further research is needed to determine the learning efficacy of simulations alone, hands-on experiences alone, and a combination of the two (tactile experience previous to simulation and vice-versa). The University of Bristol ChemLabs team is already reporting success (Harrison et al, 2009) in having students ‘practice’ laboratory experiments in simulation before the actual physical experience.

Teachers A and J highlighted the importance of simulations in freeing students from the laborious processes that so often interfere with their understanding of the underlying science concepts. They reported that using simulation software allowed them, as teachers, to spend less time than they would otherwise have done sorting out issues to do with the practical tasks and more time focusing on the key learning outcomes for the lesson.
However, in the name of instructional efficiency, might using simulations actually learn less about the real but messy nature of natural phenomena? Whilst, the two teachers both considered that this property of simulations led to student learning of the relevant concepts (as indeed Teacher A found in his post SDI tests), we don’t know that what students learned was superior to what they may learned from hands-on practical work. We may be accepting a Faustian bargain whereby we gain efficiency of a sanitized verbal learning while sacrificing the problem-solving and understanding that is associated with messy real world problems. We can’t really pedagogically approve the use of simulation solely for the efficiency gains made by skipping the more problematic practical tasks.

In mitigating the messy and complex reality of natural phenomena, simulations offer a clear advantage of focussing both teachers and students on the salient concepts that can otherwise be masked by problems associated with lab set-ups, materials, and inattention so characteristic of young secondary school children. Nevertheless this is accompanied by a substantial disadvantage signalled by Wellington’s (2000) concern that, through simulations, students will learn only sanitized and idealized science. Owen (2002) points out that “science is messy - simulations tend to be tidy”. This view is reflected in Teacher T’s comment that simulations “get rid of all the messy worldliness”, and the valuable role of simulations after authentic laboratory work for “cleaning up” the science. The simulation technology’s bias is therefore a clean and tidy outcome; this is the inbuilt expectation both of the technology and of the teachers who use it.

Taking the points made above a step further, the nature of simulation technology is to downplay and perhaps dismiss direct experience. This bias is inherent in: (a) the way the technology is so attractive to potential users; (b) the reduction in complexity and time that are part of effective hands-on inquiry based activities; (c) the sanitized outcomes and (d) administrators who would love to see simulations displace authentic costly laboratory experiences.

Teachers also need to be mindful of simplifications and even errors appearing in some simulations, both in the graphical representations and the underpinning model. A multimedia simulation is designed first and foremost for visual clarity and effect. This is of particular concern where simulations portray unobservable entities in models used by scientists to explain their observations. For instance, simulations often portray such entities (e.g. electrons) as spherical solids, but that is not how scientists view them. Science teachers must be aware of this predisposition of simulations, how it may influence students’ learning, and carefully plan when, where and how to use such simulations so that they add to rather than detract from authentic science concepts.

Another bias arises in the way children approach simulations in light of their experiences with computer games, where strategic trial and error succeeds without any deep consideration of the reality represented by the simulation. Whilst Teacher A reported that allowing “a little play on occasions” led unexpectedly to higher levels of thinking among more able students regarding electricity, current and charge, he
also noted that for many others in the class “they didn’t think about what they were doing” and constructive exploration did not result. Sins et al. (2005) too found that students don’t always approach a simulation task constructively. In an in-depth investigation of 11th grade students modelling how friction affects an ice skater, they identified students working through trial and error until they got the desired answer and not considering the reasoning behind it.

As Owen (2002) pointed out, a clear need remains to develop simulations that reflect the real difficulties that scientists encounter, and provide the possibility of addressing these difficulties. A more complete simulation environment might provide a richer vision of science and how science works as a contested and contestable activity. Though, in light of the above point, scaffolds to focus students’ attention on relevant prior knowledge would need to be included to ensure the students worked constructively with the underpinning model. Results would need to be unpacked from ‘noisy’ data and referenced to the work of other scientists, and proper attention given to explaining and defending the outcomes and methods to a variety of audiences. Only then would students be in a position to truly understand the nature of scientists’ work.

CONCLUSIONS AND RECOMMENDATIONS

These science teachers clearly moved on from their original perspective that computer simulations are an impoverished version of practical work. Their reflections conveyed that they perceive the following to be key ways that simulations impact teaching and learning in science lessons:

• increasing the scope of student experience;
• supporting exploration and experimentation;
• structuring activity and supporting active learning;
• releasing students from laborious processes; and
• enabling focus on key issues and enhancing motivation to engage with learning (Osborne and Hennessy, 2003).

However, only two of the five teachers showed awareness of the associated Faustian bargain of exchanging the “messy worldliness” of real science for a sanitized version that clearly follows simplified models of reality. Thus, as Wellington (2000) feared and Ofsted (2001) reported, science teachers are in danger of teaching only a sanitized version of science through uncritically embracing this technology.

Not surprisingly, teachers can indeed use simulations to enhance teaching and learning. However, this necessitates awareness of the inherent biases of simulation software so that appropriate care is taken when planning for their use in science classrooms. Effective science teaching and learning demands that planning for simulations go beyond simply booking the computer suite and ensuring the simulation software runs over the school network. The visual dynamism of simulations, their imagery and animation, and the opportunity to make the invisible visible are open
seductions that obscure the Faustian bargain. Digging beneath the overt and alluring promises of simulation software is crucial for making the most out of what may be gained from this technology, and recognizing and effectively addressing what is lost. For instance, the validity of science simulations, their underpinning models and representations, ought to be examined for their possible impact on students’ understanding of concepts and authentic science. Teachers must consider how they will help students map the simulation onto the real phenomenon. For instance, what role should hands-on practical work play, and should it occur before, during, and/or after a simulation experience?

In this study two of the five teachers engaged their students in discussions regarding the limitations of the models underpinning the simulations. However, they did not address the limitations or inherent biases of the simulation technology itself. Teachers must consider in what ways simulations increase and decrease the scope of student experience and learning. This is imperative because perhaps the most alluring bias of simulations is the ease to abandon the complex and messy use of real objects in favour of the clarity of an explanation made through moving visual images on a screen.

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J. WISHART


**Jocelyn Wishart**

Graduate School of Education,
University of Bristol, UK

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