Reconsidering simulations in science education at a distance: features of effective use

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Abstract
This paper proposes a reconsideration of use of computer simulations in science education. We discuss three studies of the use of science simulations for undergraduate distance learning students. The first one, The Driven Pendulum simulation is a computer-based experiment on the behaviour of a pendulum. The second simulation, Evolve is concerned with natural selection in a hypothetical species of a flowering plant. The third simulation, The Double Slit Experiment deals with electron diffraction and students are provided with an experimental setup to investigate electron diffraction for double and single slit arrangements. We evaluated each simulation, with 30 students each for The Driven Pendulum and Evolve simulations and about 100 students for The Double Slit Experiment. From these evaluations we have developed a set of the features for the effective use of simulations in distance learning. The features include student support, multiple representations and tailorability.

Keywords
simulations, distance learning.

Introduction
In this paper we discuss what needs to be taken into consideration when using simulations, when students are learning science at a distance. Computer simulations are programs that contain a representation of an authentic system or phenomenon. Because there are many computer-based activities that are called simulations, we now need to explain our definition of a simulation. Alessi and Trollip (2001) define simulations as a representation of ‘some phenomenon or activity that users learn about through interaction with the simulation’ (p. 213). In this definition, the word interaction implies that the learner and the simulation communicate interactively in some way. In this paper we are considering simulations that allow students to change some of the parameters in the program and observe what happens as a result. This type of simulation is sometimes called the interactive simulation in the literature (see Repenning et al. 1999).

Simulations have a number of features that are of particular help in the teaching of science (Wellington 2004). Simulations can help where the activities cannot be performed in the school laboratory because of the danger involved or ethical considerations of animal testing; they can help in reducing the cost of expensive laboratory experiments; it is also possible that some time consuming experiments can be performed more quickly using a simulation (although it is possible to spend considerable time exploring all the possibilities offered by a well-designed simulation); and they free up teacher time so that they can interact with students instead of dealing with the management of the experimental setup/apparatus and supervision. More importantly simulations offer an easy way of controlling experimental variables, opening up the possibility of exploration and hypothesizing. An additional advantage of simulations is presenting a variety of representational...
formats including diagrams, graphics, animations, sound and video that can facilitate understanding (Ainsworth & van Labeke 2002).

A number of science educators suggest that computer simulations offer considerable potential for the enhancement of the teaching of science concepts via, for example, enabling students to modify rules and variables to explore the science of a model, to question and test hypotheses (Enyedy & Goldberg 2004); offering simultaneous representations of the real and theoretical behaviours of a system (McFarlane & Sakellariou 2002); and supporting activities that would actively engage the learner and also offer visualization of choices and consequent effects (Rogers 2004).

Laurillard (2001) argues that ‘The [student] actions are inputs to a model, so the simulation is allowing the student to have a direct experience of the (simulated) model world; it is not operating at the level of descriptions of experience; it offers direct experience, albeit simulated’ (p. 128). She comments that simulations are classified under adaptive media as these have potential to provide intrinsic feedback (i.e. internal to the action, such as the visual trajectory of a ball kicked towards a goal) in response to their actions. Then they can use the intrinsic feedback to improve their performance and the experience is similar to a real-world one.

Students come to a learning setting with a set of beliefs and understandings about physical phenomena. They bring prior knowledge to the teaching/learning setting and this in turn influences the learning of related concepts (Driver et al. 1994; Fensham et al. 1994). In their review of the associated literature, Wandersee et al. (1994) reported that students harbour a wide variety of alternative conceptions about objects and phenomena when they enter formal learning in science. These alternative conceptions (also called prior conceptions, misconceptions or informal theories) are generally incompatible with accepted scientific knowledge.

It has been extensively demonstrated that the conventional instruction does not succeed reliably in helping students to change their alternative conceptions (Furnham 1992). Computer-based simulations, on the other hand, are powerful environments that imitate the real world and have potential to help learners to understand scientific concepts (de Jong & van Joolingen 1998; Windschitl & Andre 1998; Jimoyiannis & Komis 2001; Hennessy 2006).

As noted earlier, there are many examples of studies that have used simulations to change the prior conceptions of learners including: simple DC circuits in electronics (Carlsen & Andre 1992 reviewed in Akpan 2001; Nurmi & Jaakkola 2004); motion (Hennessy et al. 1995); elastic collisions (White et al. 1993); mechanics (Tao & Gunstone 1999); trajectory motion (Jimoyianniss & Komis 2001); velocity (Zietman & Hewson 1986); population genetics (Soderberg & Price 2003); human physiology (Windschitl & Andre 1998); and microbiology (Huppert, Lomask & Lazarowitz 2002).

Successful technology use for science teaching is dependent on, to some extent, how the teacher mediates the use of resources and, as Hennessy argues; ‘we need to consider the utility of a more “situated” view of pedagogy . . . the teachers’ knowledge of the technology itself, as well as of how a particular tool is best exploited for particular purposes, classroom/technology suite/laboratory settings, and students (in terms of age, levels of experience with the technology and the subject matter), are crucial factors in creating the conditions for effective learning’ (Hennessy 2006, p. 4).

Simulations do not work on their own, there needs to be some structuring of the students’ interactions with the simulation to increase effectiveness. This is especially so in distance learning; using technology at a distance will not be straightforward as a replacement for all these functions.

Open University context

Interactive computer simulations have been an integral part of science courses offered by the British Open University (OU) since 1980s. The simulations were used to extend students’ experience of experimental science at home and at the residential schools (Every 1987; Murphy 1987). As OU students are working at a distance, it is always necessary to provide full student support for the distance learning activities including computer simulations. Course teams (the group of people producing a course at the OU) include formative and summative evaluation of most course materials in the production schedule of their course development and materials are revised according to the evaluation results. Course teams also carry out monitoring of the course after production. Many courses with computing components are evaluated both during the development and
after they are presented to students. Another strength of this approach is that the course team is always very well informed about their students’ academic levels. For example, OU’s Level 1 science course includes, among others, a simulation of the salient variables that control a dynamic model of the Earth’s climate system called ‘Global Warming’. During the production this simulation was evaluated and results showed that the simulation encourages the student to interact with the variables, understand their sensitivities, and appreciate how a change in one variable results in changes in other variables, for example coupling (Whitelock 1998).

In the following sections we present some examples of evaluations of simulations used for science teaching in the context of students studying at a distance and discuss ways of supporting students so that their understanding of the science concepts will be facilitated.

**Simulations for distance education students**

**The Driven Pendulum**

The first simulation we consider, The Driven Pendulum, is designed for the OU’s introductory level physics course. It is presented to around 500 students studying at a distance. Originally it was designed to be used in the residential school. When a new course is designed to replace the previous one, this simulation was included in the study materials sent to students, along with other multimedia materials.

The Driven Pendulum is a computer-based experiment on the behaviour of a pendulum. It starts with a familiar and simple type of pendulum and then complexity in the form of ‘damping’ and ‘feeding energy’ is added to the system. The main aim of the simulation is to allow students to observe some of the generic features of chaotic motion and to explore ways in which different graphical representations can help in understanding this motion. The simulation screen consists of three windows. The first window displays the graphs and students have a choice of five different displays:

- $\theta$ vs time (angle as a function of time)
- $d(\theta)/dt$ vs time (component of angular velocity as a function of time)
- $d(\theta)/dt$ vs angle (component of angular velocity as a function of angle)
- direction vs time
- revolutions

The second window is a pendulum animation and the last window has the pendulum parameters (see Fig 1).

The development of the graph can be observed by the students and the animation provides visual information about the position of the pendulum. Students can specify the parameters (Mass, Length, Initial angle, Initial angular speed, Pivot amplitude, Pivot frequency, Experiment duration), determine how many samples per drive cycle will be used to form the graph and whether to observe the display in real time or fast processing. An additional pop-up menu provides students with facilities to examine the motion of the pendulum in detail by offering: Autoscale, Range, Fit damped curve and Memorise (which superimposes the previous graph onto the present one) facilities.

This software has been produced by software designers at the then Centre for Educational Software of Academic Computing Service at the OU. The underlying mathematical model and algorithm have been provided by the OU’s Physics Department.

The use of this simulation has been evaluated (Scanlon et al. 1997). Some of the results from this evaluation will be presented here to support our argument that use of simulations in technology-enhanced environments requires close attention to supporting students in their interpretation of the physical phenomena under consideration. One way of achieving that support is by providing activities and representations that will clarify different interpretations of the results observed in the simulation. For example, this simulation provides several representations that show how the pendulum behaves under different conditions. These representations are presented along with the experiment notes and students are asked to observe the behaviour of the pendulum with given parameters, under different representation modes, to clarify what they represent. The notes accompanying the simulation prepare students, step by step, to try several features of a simple pendulum, a damped pendulum, experiment with resonance that is observed when an oscillatory system is excited with another oscillatory system (i.e. up and down movement provided at the pivot point of the pendulum) and in the final section students are introduced to the chaotic pendulum. At each step students are provided with some parameters to examine the behaviour of the pendulum and suggestions are made regarding the best representation(s) to observe this behaviour. Optional exercises are
recommended for further experimentation. Each section also has an explanatory part regarding onscreen behaviour so that students will be aware of the theory underlying the observations and what they are supposed to observe. These notes support students in understanding the behaviour of the pendulum and make them aware of what they should get out of the simulation. As further complexity is gradually added to the system it is made easier to understand how a simple system can create complicated behaviour. The notes also include, at the end, a section on facilities available in the simulation.

The simulations always contain written and/or online help systems clearly explaining to students what they are supposed to get out of the activity, sometimes accompanied by a number of self-assessment questions.

The findings for this study were based on questionnaires filled in after the experiment, observations, video and audio recordings of some sessions (to gain access to the conversations which the pairs had while using the simulation), and individual and group interviews with students and tutors. The questionnaire results showed that students understood the experiment notes and found the simulation motivational. Out of 30 students answering the questions related to experiment notes and motivation, only four of them did not find the notes clear and the software motivational. When asked about the most important advantage of doing this experiment as a computer simulation, half of the students stated that they would learn more in the same amount of time, and almost the same number (14 out of 30) that it gave better results. The observations revealed that many of the students used the simulation to check physics equations in the experiment notes because they were interested in the underlying model of the simulation and wanted to experiment to see what it was like. In the interviews after the experiment students were asked about their perception of the pendulum simulation experiment. The data revealed that students saw the simulation as an idealized system. They found it quite useful and a very good facility for conducting a number of experiments in a limited time. The following selected quotes from the observation/video recordings of pairs of students show that the students were testing the fidelity of the software, their own hypotheses and were using multiple representations to further their understanding of the behaviour of the pendulum.
It would be interesting to see what the program set out for G. [G is the gravitational constant]
(Students are talking about the value of the gravitational constant in the simulation.)

1. In theory it should go all the way around!
2. Yes it is balanced, it can fall either way.

(Students are looking at the animation when the pendulum at the highest point and trying to guess which side it will fall.)

A. I am not quite sure what the curves here are.
B. Did you observe it developing?
A. Oh, it is spiral.
B. Looking at real time makes it clear.

(One of the students is looking at the graph that is depicting the behaviour of the pendulum as a series of circles and the other suggests observing the graph forming in real time.)

I wonder if it would be chaotic as you keep increasing the frequency, suppose you went up to 2000, would it always continue or just come a point you pass out of this and it starts to behave like a normal pendulum.
(A student is pondering the effect of increasing the frequency on the behaviour of the chaotic pendulum.)

This simulation is an example of how students can be supported to make good use of an interactive simulation. By providing guided introduction to a complex topic and also explaining the theoretical model underlyng the system under consideration, students are supported but also free to experiment to test their own hypotheses about the behaviour of a pendulum. It also shows that representations of natural phenomena need to be used very carefully and by taking into consideration that they can create confusion about the subject if necessary explanations are not provided. The experiment notes for this simulation were revised accordingly after this evaluation study.

Evolve

The second simulation we consider is a project carried out by students at a distance and on their own. The students are doing a level 2 science course on evolution and most of them have previous experience of studying one or more science courses. The simulation forms one of four project options offered to students and it is assessed. It is concerned with natural selection in a hypothetical species of a flowering plant. It simulates what happens when two populations of the species come into contact and begin to hybridize after a period of reproductive isolation during which, to some extent, they diverged genetically.

It is designed to help undergraduate students better understand the concept of heritability and for the course on evolution to provide students with an opportunity:

1. to consolidate their understanding of the arguments for evolution by means of natural selection.
2. to experience planning and carrying out systematic investigations of a relatively complex system.

The activity was built on a project carried out with campus-based students a number of years ago. However, for students learning at a distance there was a need to adapt the activity so that students would be able to understand the basic attributes of the biological system before they could investigate the system in more detail. In this project the students are required to interpret the results according to the principles of evolution by natural selection. As this meant that there was the possibility that the students could misunderstand the model completely, a carefully designed new activity was prepared.

The new activity required students to:

- First run the simulation under ‘controlled’ conditions (with the given parameters and instruction on running the simulation) while being provided with some guidance on the output produced.
- Then they are provided with a formal description of the model upon which Evolve is based. They need to understand the model to be able to interpret runs of the program correctly.
- The next step is to consider outputs from ‘controlled’ runs bearing in mind the details of the model. Their understanding of the model is checked as they are asked to describe the changes in the populations and then interpret them in terms of evolution by natural selection in the first part of their project report.
- Finally, they are given some more information about the parameters that can be altered during the course of other investigations. They are then asked to investigate the effect of changing parameters on the resulting population. This forms the second part of the project.

Figure 2 provides an output from a controlled run of the simulation. The small window shows the
parameters a student can manipulate and the bigger window displays genetic composition and frequency distributions for plants flowering in the 5-week period as well as the number of weeks these plants stay in flower. As there are many variables presented in these charts, students need to study the introductory notes and understand the system to be able to carry out the project effectively.

In this simulation we see a lot of support to facilitate students’ understanding of a challenging science concept. Rather than informing students that they need to know about ‘evolution by natural selection’ to carry out the assignment, they are introduced to the simulation, model and principles through a series of activities; in an order that will make sure they are introduced to the concept in a way that makes it easier to understand and reduces any possible misunderstandings.

In the evaluation of this project we used a diary technique. The project diary contained an introductory page, pre- and post-project questions and session pages dealing with students’ activities each time they did work related to the project. Post-project questions included:

- What do you think you have learnt from the project?
- What kind of skills have you developed?
- How do your results fit in with the theory of natural selection?

One of the things they were asked was to write down what they thought they have learnt from this project. The following quotes selected from the sample ($n = 15$) shows that students thought they understood the concepts introduced in the project.

S1. A much better understanding of both hybridization and of how selection processes actually work in generation after generation.
S5. Improved knowledge of speciation effects. Some difficulties in computer modeling such processes.
S7. How the process of natural selection operates?
S8. I have a clearer idea of how evolution works on populations.
S14. I learnt a lot about natural selection and how it affects populations.
S15. Demonstration of the long-time scale (many generations) involved in natural selection, importance (or otherwise) of hybrid fertility and different reproductive strategies.
Student answers relating to skills they developed as a result of doing this project were:

S2. None that I did not already have, except that the project made me think about the question in different ways.
S5. Some skill in computer modeling but not much.
S7. Ability to predict what may happen to population when selection pressures are altered.
S11. I can use a new computer program. I can look at several interacting parameters and appreciate that easy explanations are rarely good enough.

In terms of fit of simulation results with the theory of evolution, one-third of students thought that they fitted very well, more than one-third was not sure or they thought they did not have enough data to answer this question. When asked to compare their findings with results they could have got by collecting and synthesizing data from an actual species of plant, one student said ‘it would have been difficult to get similar results from real populations because of the time involved (several years) and the much more complex genetics of real plants’. The majority of students commented on the difficulty of setting up a similar experiment in real life instead of comparing results.

Almost all students indicated that they had previous experience of doing practical projects, mainly in previous OU courses. These answers from students and the evaluation studies carried out on this course show that students were able to focus on the investigation required for the project and learning objectives for this simulation were achieved by the majority of students.

The Double Slit Experiment

Our final simulation is one of several simulations designed for the introductory physics course, Physical World, presented by the OU. The course gives a broad introduction to physics and its applications and is presented to around 500 students per year, who are learning at a distance. One of the components of the course is tutorial-type multimedia programs covering a selection of topics in textbooks. These tutorials are sent out to students on a CD and students use them on their own. Most tutorials are based on simulations (e.g. a simulation of the three-body problem in the program Stepping through Newton’s Laws) and some are based on simulated experiments (e.g. sharing out energy in gases: exploring equilibrium distributions). In this paper we will look at a simulation about electron diffraction, called ‘The Double Slit Experiment’. In these simulations students can carry out investigations using single and double slit arrangements to examine the resulting electron diffraction patterns and can vary parameters such as slit width, slit separation, electron gun voltage and electron gun current (see Figs 3 and 4).

The two screenshots from this experiment show how student support is provided when they are working with this simulation. They are provided with multiple representations of the simulation: the experimental apparatus showing the actual values of parameters, the view of the black screen showing the pattern of electrons hitting it, and also a graph displaying the number of electrons found on the screen at certain distances from the centre. These screens are all adaptable and any changes made by students to the parameters are reflected in the appearance of the apparatus and resulting electron screen and graph. There is an audio commentary to explain to students the experimental setup and the concepts covered. This provides a narrative for students to follow, similar to accompanying notes. The main points are presented at the side of the experimental window as bullet points for each part.

There are questions related to the experiment (see Fig 3). A wrong answer from the student triggers the system to help the student as follows:

- First of all student is guided towards the correct answer, and another chance to answer is given.
- If the answer is still not correct, an explanation and the answer is provided.
- At the third attempt the answer is provided with a detailed explanation.

Even if students answer correctly in their first attempt an explanation is provided to ensure that students are not just answering the question by trial and error or arriving at the right answer by an unacceptable method, thus making students reconsider any alternative conceptions they may have.

The summative evaluation data for these multimedia tutorials were based on questionnaires sent to students, interviews carried out in the residential school of the course and on the end-of-year questionnaire. We had 62 returned questionnaires from students (35% return rate) and 19 pairs of students were interviewed in the residen-
Fig 3 Double Slit Experiment screen showing the apparatus.

Fig 4 Double Slit Experiment screen showing student support after an initial wrong answer.
tial school of the course, a total of 100 students. The questionnaires covered experience of technology mediated learning, students’ own perceptions of learning from the programs, usability of programs, help required, time spent using the programs and use of specific facilities within the programs.

Part of the questionnaire focused on the use of simulations. Screen dumps were included with the questionnaires to help students remember the details of the programs. The questionnaires had two sections. The first section asked the same general questions about features that were common to all packages, such as navigation, use of audio, clarity of controls, use of simulations, etc.

Most of the programs had simulation facilities and we were interested in finding out if students carry out their own investigations using the environments provided. About 72% of students stated that when using simulations they always or most of the time changed the value of a parameter and re-ran the simulation to carry out their own investigation.

As programs contained specific additions like pictorial representations, videos and real research simulation, facilities to give students opportunities to change parameters in simulations and several buttons or edit boxes to animate phenomena being presented on the screen, thus the second part of the questionnaires included questions on these features.

The majority of students felt that the time spent using these programs was well spent (ranging from 65% to 95% for different programs), the feedback provided by the program was useful (more than 80% for all programs), they were an effective way to learn (67–93%), and helped their understanding (67–93%), and it was generally clear for them what they had to do while using these programs (80–95%).

When asked about their perceptions of the simulations most students said that they used them and found them very useful. Interviews with the students revealed that simulations were one of the most used among the computing components of the course. A selection of comments from students is given below:

Usefulness of the simulations:

It has been very useful to visualize scientific phenomenon such as waves, fields, forces, etc. which one obviously cannot see in real life.

Learning from the simulations:

What an electron scatter image actually looks like. Reinforced reason why photons (light) is not used to detect electrons.

Best thing about the simulation as a learning tool:

Can be reviewed again and again until you do follow it.

This activity provides an example of using a simulation as an effective learning tool to perform appropriate tasks. The simulation asks students to manipulate parameters, encourages them to make predictions and also provides explanations for observations. This combination of simulation and teaching makes this approach a powerful teaching medium and especially suited to distance learners.

Discussion

We have reviewed some computer simulations designed to be used by students of science working at a distance with the aim of considering how students can be supported in the learning required.

Simulations can play an important role in science learning. On the other hand their use is not as straightforward as it seems. Many researchers emphasize the importance of a good instructional plan when using simulations. de Jong et al. (1994) argue that the reason for finding no conclusive evidence for effectiveness and efficiency of simulations, despite their popularity in instruction, is the lack of support for learners in some simulations, that is, if learners encounter difficulties they may not overcome these on their own.

Effective simulations require several properties to help students understand scientific concepts better and also help them revise their alternative conceptions regarding physical phenomena. If the learner is using the simulation on his or her own it becomes even more important that there is provision to support learning and the simulation has some features that help better learning of difficult concepts of science. We list these below:

1 To be scientifically useful, simulations should be based on real events and data. Also as the discussion on the fidelity and complexity of simulations shows, to get the correct level of reality will help students’ learning.
All three simulations considered in this paper are based on real data that can be reproduced in a scientific experiment. They also represent actual events and not hypothetical situations. Our findings showed that students were trying to test the authenticity of the pendulum simulation during their experiment by checking the equations and physical constants against the results from the simulation. Authenticity of the Evolution experiment was also an issue for students and they did not think that they would get the same results from a real experiment if they had the possibility to run it for 100 generations for real. This shows that simulations need to have a correct level of representation of the real world. Too simplified representations may confuse learners but exact representations on the other hand may make them over complex. In addition, for simulations that are run in a fast processing speed, a facility to run it in real time should be provided to give the students the opportunity to observe the parameters at real time. Both physics experiments have this facility. In the natural selection in plants simulation, Evolution, this does not apply as it only presents the results in chart form. The simulation only presents the genetic results of hundreds of generations. All the simulations can be repeated an endless number of times and it is very important that a student can try different setups and see the results. Students’ comments show that this is a very valued aspect of simulations.

2 Use of multiple representations, graphs and an opportunity to observe any graphs forming while the experiment is running (in real time) is also a very useful feature for simulations.

Many simulations provide multiple representations of the same or related concepts, and this can enhance students’ understanding (Goldberg 2001). In their study of a multi-representational design framework to develop and evaluate a dynamic simulation environment, Ainsworth and van Labeke (2002) proposes that multiple representations are used for diverse pedagogical goals and one line of research has focused on the unique potential and problems of learning simultaneously with more than one representation. On the other hand the research dealing with multi-representational learning is still in progress and developers of simulations need to pay attention to research dealing with the conditions under which more than one representation will be beneficial.

The two physics simulations reviewed make use of multiple representations to a great extent. For example five different graphs to depict the behaviour of the pendulum provide students with detailed information about what is taking place. In The Double Slit Experiment students can see the experimental apparatus, see the graphs depicting the results of the experiment and also can see the pattern formed by electrons on the black screen. Especially in the area of physics, multiple representations seem to be a good way of helping students to understand complex phenomena. The Evolve simulation presents only a limited multiple representations of the phenomena but it is possible to see the change over time in genetic makeup of the 100 generations of a plant species and the flowering time.

3 For all simulations, facilities to tailor activity to student ability levels and a narrative for students to follow ought to be provided either online in the simulation or by the accompanying notes. This can be done more effectively if the student population and their needs are known to instructional designers.

In all three simulations students are provided with detailed subject matter knowledge in the form of accompanying notes and/or online support facilities (providing information at the moment it is immediately needed by the learner). Students are guided to produce and test hypotheses and design experiments for the Evolution simulation as one of the main focus of their project work and in physics simulations they are given opportunities to experiment by hypothesizing about the expected results of questions posed in the notes. Questions included in the notes and online text facility gives students an opportunity to make predictions and test them. All these features are mentioned by de Jong and van Joolingen (1998) when they discuss how simulations may be combined with instructional support to overcome difficulties that learners may encounter: direct access to domain knowledge, support for hypothesis generation, support for the design of experiments, support for making predictions and support for regulative learning processes.

This advice is consistent with Fyle’s (2003) suggestions that to enhance conceptual change by using simulations we need to provide: (1) functionality that allow learners to compare their existing conceptions or misconceptions with the ideal or correct conceptions of a
particular domain, (2) help resources that provide detailed explanatory support that helps learners understand particular concepts or sections within the domain being studied, (3) functionality that provides learners with the opportunity to have multiple explanatory representations of different aspects of the domain presented to them, and (4) provide functionality that provides adaptively to levels of expertise.

Simulations have been used in science education since the early 1970s. Their continuing popularity within the OU and elsewhere has required us to consider carefully how best they can be used. Our review of some distance learning examples together with the literature emerging from classroom studies of simulations have allowed us to construct a list of features to be considered to enable the most effective use of such simulations. Contemporary promoters of technology continue to be interrogated about the effectiveness of the solutions they propose. The use of simulations is one area in which such evidence has been collected. However, we have shown here that the success of simulations as effective learning tools is dependent on how simulations are used.

References


