Constructivist Simulations: A New Design Paradigm

BARRY HARPER,
University of Wollongong
Northfields Ave. Wollongong
NSW, Australia, 2500
barry_harper@uow.edu.au

DAVID SQUIRES,
King’s College London
Cornwall House Annex
Waterloo Road, London, SE1 8WA
david.squires@kcl.ac.uk

ANNE MCDougall,
Monash University
Clayton, Victoria
Australia, 3168
Anne.McDougall@Education.monash.edu.au

The possibilities afforded by new multimedia technology, combined with contemporary ideas about learning, have opened up new design opportunities for educational simulations. In particular, the use of sophisticated multimedia environments has made the design of experiential simulations, in which the learner plays an authentic role carrying out complex tasks, a much more tractable design task. This contrasts with an earlier emphasis on the design of simulations which allowed learners to explore the behaviour of systems in symbolic terms—so called “symbolic” simulations.
In this paper we describe the emergence of a new design paradigm for educational simulations, which is based on research and development of two simulations informed by constructivist theories of learning. We propose that the experience gained in the implementation of these simulations has led to an example of a new paradigm: the “hybrid paradigm” which combines symbolic and experiential approaches from a pedagogical perspective.

Simulations entered the broad educational scene in the late 1950’s. They were popular in the USA in the 1960s, but declined in use in United States’ classrooms with the advent of the basic skills test (Gredler, 1996). The simulation paradigm formed the essential theoretical rationale for the early major computer assisted learning initiatives in the UK, for example, the National Development Programme for Computer Assisted Learning (1973-1977) and the Computers in the Curriculum Project (1975-1990). However, by the mid 1980s the use of general-purpose software tools had become the dominant paradigm. In Australia, both games and simulations have had a long history of extensive and successful use and do not seem to have “gone out of favour” at any time since their introduction (Cavallari, Hedberg, & Harper, 1992).

The possibilities afforded by new multimedia technology, combined with contemporary ideas about learning, have opened up new design opportunities for educational simulations. In particular, the use of sophisticated multimedia environments has made the design of experiential simulations, in which the learner plays an authentic role carrying out complex tasks, a much more tractable design task. This contrasts with an earlier emphasis on the design of simulations which allowed learners to explore the behaviour of systems in symbolic terms—so called “symbolic” simulations.

In this paper we describe the emergence of a new design paradigm for educational simulations, which is based on research and development of two simulations based on constructivist theories of learning. The first product, *Investigating Lake Iluka*, is an experiential simulation. Classroom evaluation of this product identified learner needs, which led to design recommendations for a further experiential simulation, *Exploring the Nardoo*. However, we propose that the implementation of these recommendations has not led simply to an improved experiential simulation, but to an example of a new paradigm: the “hybrid paradigm” which combines symbolic and experiential approaches from a pedagogical perspective.
CONTEMPORARY THEORIES OF LEARNING

In her review of theories of learning and multimedia applications Atkins (1993) suggests that learning with interactive courseware delivered on advanced technology platforms can be categorised in terms of two underlying views of learning: the behavioural and the cognitive. Within the cognitive category she distinguishes between “weak” artificial intelligence and constructivist views of learning. Winn and Snyder (1996) have argued that as educational technology was established as a discipline when behavioural principles dominated psychology, behaviourism initially provided the most common instructional design. As theories of learning have developed and educationists have gained more experience of using computer based technology, there has been a shift of emphasis from the behaviourist paradigm, through what Atkins (1993) has called the weak artificial intelligence approach, to a constructivist view. For most educationists constructivism offers far more scope for realising the possible learning benefits of using information and communication technology.

Many writers have expressed the hope that constructivism will lead to better educational software and better learning (Brown, Collins, & Duguid, 1989; Papert, 1993; Jonassen, 1994). They stress the need for open-ended exploratory authentic learning environments in which learners can develop personally meaningful and transferable knowledge and understanding. The lead provided by these writers has resulted in the proposing of guidelines and criteria for the development of constructivist software (Rieber, 1992; Cunningham, Duffy, & Knuth, 1993; Honebein, Duffy, & Fishman, 1993; Driscoll, 1994; Grabinger & Dunlap, 1995; Savery & Duffy, 1995; Duffy & Cunningham, 1996; Grabinger, 1996; Squires, 1996; Hannafin & Land, 1997; Grabinger, Dunlap, & Duffield 1997). A recurrent theme of these guidelines is that learning should be authentic. A review of the literature points to three seminal concepts, which originate from the notion of authenticity: credibility, complexity, and ownership.

For learners to feel that an environment offers credible opportunities for learning they need to be able to explore the behaviour of systems, environments or artefacts; one way to do this is through working with simulations. The environment should provide the learner with intrinsic feedback which represents the effects of the learner’s action on the system, environment, or artefact. Learners should be able to express personal ideas and opinions, with the environment providing a mechanism for the articulation of these ideas. In addition, learners should be able to experiment with ideas and try out different solutions to problems. In this sense they should be able
to adopt multiple perspectives by engaging in activities which support multiple knowledge representations, to experience varied cases and contexts, and to have varied purposes for knowledge (Ainsworth, Bibby, & Wood, 1997).

Grabinger and Dunlap (1995) emphasise that learners should be presented with complex environments that represent interesting and motivating tasks, rather than contrived sterile problems. Only in complex, rich environments will learners have the opportunity to construct and reconstruct concepts in idiosyncratic and personally meaningful ways. Learners may need help in coping with complexity. Strategies to help learners include scaffolding (Krajcik, Soloway, Blumenfeld, & Marx, 1998), anchoring (Cognition and Technology Group at Vanderbilt, 1990) and problem based environments (Tobin & Dawson, 1992; Grabinger, Dunlap, & Duffield, 1997).

A sense of ownership should be a prominent feature of learning. The established idea of locus of control (Wellington, 1985; Chandler, 1984; McDougall & Squires, 1986; Blease, 1988; Goforth, 1994) is relevant in this context. Working in software environments which provide high levels of user control will help students feel that they are instrumental in determining the pattern and process of the learning experience, and thus develop a sense of ownership. Metacognition, in which learners reflect on their own cognition to improve their learning, has been advocated by a number of writers, for example, Scardamalia, Bereiter, McLean, Swallow, and Woodruff, (1989) and Papert (1980). It is claimed that by a conscious personal appraisal of cognitive processes, an individual can improve his or her capacity to learn. Clearly, for this to be effective the learner must feel a sense of ownership of the learning.

THE SIMULATION PARADIGM

The use of simulations as learning environments has a long history. Kemmis, Atkin, and Wright, 1977 described simulation as the classic manifestation of the “revelatory” mode for the use of educational software. Initial claims for the educational benefits of using simulations tended to emphasise pragmatic solutions to classroom problems. Processes, which take a long time, for example, population growth or genetic change, or which happen very quickly, for example, changes in impulsive force during a collision, are possibilities for simulation. Difficult, dangerous, or expensive processes are also candidates for simulation, for example, experiments with radioactive materials. The study of large-scale complex systems, such as the
ecology of natural habitats or major industrial processes, also provides a rationale for simulation.

As experience of the design and use of simulations has grown, claims have been made from a more cognitive point of view, based on a belief in the merits of exploratory learning. Bliss and Ogborn (1989) epitomise this view in describing computer based simulations as programs in which the computer acts as an exploratory tool, supporting a real world activity while facilitating user understanding of the processes, which may be otherwise inaccessible, in complex dynamic systems. This cognitive perspective is intrinsically compatible with a constructivist view of learning.

Recently Gredler (1996) has categorised simulations as either symbolic or experiential. Symbolic simulations are a dynamic representation of the behaviour of a system or world, a set of processes or phenomena. The behaviour that is simulated is usually the interaction of two or more variables over time, and the learner can manipulate these variables in order to discover scientific relationships, explain or predict events, or confront misconceptions. A simulation of a laboratory experiment provides a classic example of a symbolic simulation. In contrast to an experiential simulation, learners using a symbolic simulation are not usually regarded as functional elements of the situation. As such they do not have a vested interest in outcomes, possibly making the feedback provided by the simulation of less personal interest.

By contrast, experiential simulations aim to establish a particular psychological reality and place learners in defined roles within the reality. Gredler describes the essential components of an experiential simulation as “(a) [sic] a scenario of a complex task or problem that unfolds in part in response to learner actions, (b) a serious role taken by the learner in which he or she executes the responsibilities of the position, (c) multiple plausible paths through the experience, and (d) learner control of decision making” (1996, p. 523). Role playing simulations of environmental planning are classic examples of experiential simulations.

**INVESTIGATING LAKE ILUKA: AN IMPLEMENTATION OF THE EXPERIENTIAL PARADIGM**

A CD-ROM product, *Investigating Lake Iluka*, in Gredler’s terms an experiential simulation, is based on the concept of an information landscape that incorporates the biological, chemical, and physical components of a range of ecosystems that make up a coastal lake environment. Users are given some problem solving strategies to investigate this information in a
variety of ways using the range of physical tools provided. They can collect biological, physical, or chemical data using the tools, as well as media information and “construct” their own understanding of the basic ecology concepts embedded in the package. The design and use of the package in classrooms has been extensively reported (Harper, & Hedberg, 1996; Harper, Hedberg, Wright, & Corderoy, 1995; Hedberg, Harper, Brown, & Corderoy, 1994; Harper, Hedberg, Brown, & Corderoy, 1993).

Evaluation of the package by teachers and students in the early stages of completion resulted in a number of insights into the design features of the application. One of the package reviews was achieved by introducing it to two classes of Year 11 students (n=48), aged 17 years, studying the topic of ecology. Extensive observations were made of the student use of the package, as well as their response to the perceived outcomes of its use (Hedberg et al., 1994). Students working with the package expressed a need to have:

- greater access to the rich resources to express their ideas and solutions to problems;
- greater fidelity in the representation of the context and the authentic tasks to be undertaken; and
- additional support for the problem solving process and for hypothesising solutions through what they termed “what-if” scenarios that is, scaffolding of the cognitive processes.

These needs provide clear directions for the further development of experiential simulations.

**EXPLORING THE NARDOO: A FURTHER IMPLEMENTATION**

A following package, *Exploring the Nardoo*, developed by the designers of *Investigating Lake Iluka*, attempted to address these issues by increasing the fidelity of the representation of the context and also by offering scaffolding tools in the form of cognitive tools (Harper, Hedberg, Corderoy, & Wright, in press) for learners. The package can be described as an experiential simulation, at the top level, but the package also incorporates more traditional symbolic simulations for supporting learners in what the designers call “What-If” investigations components of complex water management issues.

*Exploring the Nardoo* simulates a changing inland river catchment area from its pristine state last century to a development affected environment
today. The software has been designed to complement work in ecology and physical geography. From an ecological perspective the aim is to support the study of interactions between living organisms and their chemical and physical environments, with particular emphasis on the impact of humans.

A sense of authenticity is conveyed through the visual representation of the environment. Learners have access to a rich set of resources and data that are both embedded in the river environments in situ, through hot buttons, and also in a simulated “Water Research Centre” (Figure 1) through interface metaphors such as books and newspaper clippings. The resources in the Water Research Centre include a plant and animal book, containing descriptions of all of the plants and animals of the river, lists of television news reports and interviews, radio news reports, newspaper cuttings, a filing cabinet containing technical articles and reports on the various investigations, a “Presentation Booklet” which contains support for learners in note taking, filing notes and producing reports and a “Text Tablet” for editing and elaboration of notes and data collected during investigations.

Figure 1. The simulated Water Research Centre

Learners have access to facilities and tools provided by a “Personal Digital Assistant” (PDA) Figure 2, which provides users with a multimedia notebook for collection of any of the resources in the package, including video, audio, graphics and text, a viewer for viewing the video and graphic resources, a set of measuring tools to take measurements on the river, user
support through a help file, and navigation tools. Chemical and biological data can be collected by selecting sampling locations and requesting values such as temperature, pH level, turbidity, algal cell count, and coliform bacteria. As its name suggests, the PDA provides a way of personalising a learner’s interaction with the software, hopefully leading to an enhanced sense of ownership.

![Image of Personal Digital Assistant](image_url)

**Figure 2.** The Personal Digital Assistant

In terms of Gredler’s essential components of an experiential simulation, learners are:

- prompted by 3 researchers in a Water Research Centre to take on a role as a research assistant to help them solve problems and carry out investigations;
- asked to support research of solutions to a complex problems posed, by presenting an argument, based on one of 9 different genre models. The complexity of the task unfolds as the learner investigates the issues. They are encouraged to use the rich set of resources to argue their view;
- offered a broad range of investigations from a selection on an ‘Investigations Notice Board’, allowing users to take multiple paths through the
package to achieve their goals; and
- given control over deciding how to access the embedded information
  and how they complete their investigation.

Additionally, 3 symbolic simulations have been embedded as tools for
learners to continue their investigations. The symbolic simulations allow the
learner to manipulate variables and examine the consequences, that is, they
have been expressly designed to scaffold the experiential component of the
package, offering learners a means to test their hypotheses and problem so-
lutions. The simulators illustrate “whole catchment level” water demand
management, a blue-green algal bloom, and personal home water use. The
designers of this package have assumed the provision of well defined
exploratory domains, in the form of symbolic simulations directly relevant
to the open ended experiential exploratory space provided by the umbrella
experiential simulation, that will help learners focus on the relationships be-
tween specific relevant variables.

To illustrate their use, one experiential investigation involves solving a
problem related to a blue green algal bloom that has developed on the Nar-
doo river. The problem is posed, through one of the researchers, Stephen, in
the following way:

**LOCALS ILL AFTER SWIMMING IN RIVER**

There have been a number of reports of illness among people using
the Nardoo River for swimming. There have also been reports of dead
stock floating in the river in the Walloway Region. The problem
seems to be associated with a severe blue-green algal bloom.

**YOUR TASK:**

Explore the affected regions and gather information about the issues.
Prepare an information brochure detailing what an algal bloom is,
what causes it, how it can be dealt with, and what problems it causes
the community.

Learners can collect a series of video news reports, radio news reports,
newspaper reports, and article reports stored in the Water Research Centre
filing cabinet. The resources not only supply factual information, but also
opinions on possible solutions from experts and interested locals. Addition-
ally, learners can make measurements in the river, using the inbuilt PDA
measuring tools (Figure 2) to determine the chemical and biological content
of the river. To scaffold learners in their investigation of this complex issue,
a symbolic simulator, the blue-green algal bloom simulator, has been included (Figure 3).

The simulator allows learners to test their hypotheses by changing the input variables and observing the output variables, instantaneously and over time. Additionally, the simulator allows learners to link the numerical and graphic output back to the experiential element of the package by offering a visual representation of the river. Learners can, for example, hypothesise that flushing the river will solve the problem—a solution offered by one of the local farmers in a news interview. Figure 4 illustrates how the simulation shows the variation in the cell count with time over six months for (a) the unflushed river, (b) one river flush, and (c) two river flushes. From this output it is evident that flushing the river is a short-term solution and a long-term solution is needed to solve the problem.

Figure 3. Pictorial representation of the blue-green algal bloom symbolic simulation output
The link between the experiential simulation and the symbolic simulation is reinforced by providing learners with the option to select a pictorial representation of the effects of flushing the river as shown in Figure 3.

Using symbolic simulators to scaffold learners’ uses of experiential simulations has a number of constructivist features:

- They greatly enrich the “quality” of the problem solving process for the user by providing unhindered access to act and become immersed in a “real” situated process, manipulating the various causal parameters and testing hypotheses without a “real” consequence or risk and in a time frame which is convenient and manageable. The simulations have been designed to enable “the learner to ground their cognitive understanding
in their action in a situation” (Laurillard, 1996).

- The simulators in *Exploring the Nardoo* offer strong visual representation of the context of the simulation and multiple inputs and outputs. For two of the simulators the outputs can be viewed as visual representations, numerical representations, or as graphical representations. In the third simulator the output is numerical and is also supported with learner scaffolding through a talking intelligent guide.

The issue of the naive expectation that learners will naturally be able to deal with unconstrained complexity implied by free exploration is addressed in these simulators by setting them in the context of the overall package. At this level, the simulators are viewed as cognitive tools for learners, helping them to resolve a problem posed within the Water Research Centre.

**THE HYBRID PARADIGM FOR EDUCATIONAL SIMULATIONS**

The design rationale of *Exploring the Nardoo* was to develop an improved experiential simulation by incorporating improvements intended to address issues raised in the evaluation of *Investigating Lake Iluka*. First, more extensive use was made of multimedia features to improve the fidelity of the simulation. Second, auxiliary symbolic simulations were included to scaffold the use of the experiential simulation of river management. On reflection it appears that the second design imperative is more than just an improvement to the implementation of the experiential simulation paradigm; rather it is suggestive of a new “hybrid simulation” paradigm for the design of educational simulations, which harnesses linked symbolic simulations as a pedagogical tool to help users realise the cognitive benefits of using experiential simulations.

Experiential simulation provides a comprehensive design framework for addressing the three “constructivist issues” of complexity, credibility, and ownership. This is illustrated by the design of *Exploring the Nardoo*. Learners are encouraged to develop a sense of ownership by assuming a serious management role in which they have the opportunity to make influential executive decisions. The management process and decision making procedures are presented in a credible fashion through the use of a multimedia interface which mimics a real-life management setting. Complexity results from the provision of an extensive and diverse set of resources and tasks giving multiple plausible paths through the experience of using the software.

Paradoxically, the complex nature of experiential simulations is both a
strength and weakness. While complexity may be necessary to provide authentic learning environments, too much complexity can make learners feel insecure and lose track of learning objectives. This implies that they need help in coping with complexity. The provision of well-defined tasks, as in Exploring the Nardoo, can help learners to cope with complexity. Providing auxiliary cognitive tools to scaffold learners as they address complex issues is another approach.

Symbolic simulations typically feature a clearly articulated representation of a system or process. Users can manipulate complex environments in relatively simple ways; the design of the simulation has reduced apparent complexity. As such, symbolic simulations are candidates to scaffold learners in their attempts to cope with the complexity inherent in experiential simulations.

The hybrid simulation paradigm exploits the scaffolding potential of symbolic simulations within the framework of an experiential simulation. Exploring the Nardoo provides examples of this approach. The water simulator, in which learners can explore the effects of domestic activities on water consumption, provides opportunities for learners to develop a general awareness of water management issues. The blue-green algal bloom simulator and the dam management simulator are specifically linked to the river simulation, for example, as environmental conditions are varied pictorial representations of the changing state of algal growth in the river are shown on the screen. In these two simulations there is a dynamic exchange of data between the “what-if” symbolic simulations and the experiential simulation.

The notion of using dynamically linked experiential and symbolic simulations provides a new approach to addressing a major pedagogical problem inherent in constructivist approaches to learning and teaching: How can learners be provided with authentic complex learning environments in such a way that the complexity encourages exploration and experimentation as opposed to creating confusion and insecurity? The hybrid simulation paradigm opens up the possibility of a new design paradigm for educational simulations.

References

Atkins, M.J. (1993). Theories of learning and multimedia applications: An


Acknowledgements

This work is based on research and development conducted by The Interactive Multimedia Learning Laboratory, and the Research in Interactive Learning Environments group at the University of Wollongong. Additionally, the authors would like to acknowledge the contribution of John Hedberg, Rob Wright and Robert Corderoy to the ideas reported in this work. The initial ideas for this paper were developed by the authors during study leave taken by Dr Barry Harper at the School of Education, King’s College.