THE AUSTRALIAN JOURNAL OF
EDUCATIONAL TECHNOLOGY

The use of interactive computer simulations in training

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Introduction

Trouble strikes on the 800 mile trans-Alaskan pipeline with no time for hesitation. So when Martin Colt detects a crude oil leak, he quickly diagnoses the problem and hits the appropriate switches on Pump Station No.8's control panel to close a valve 25 kilometres down the line. Crisis is averted. Martin, an operations technician notes the time it took for him to complete the task.

Although only a simulation, the above scenario is effective in providing feedback on Colt's performance and preparing him for potential crisis situations. Due to the risk involved in this type of scenario and many like it, it is imperative that performance standards of 100% are achieved. Any less would be unacceptable - more so when human life is at risk. In order to achieve such performance, allowing Martin to practice on the live system would not be feasible. By providing a simulated environment, Martin learns by actually performing the activity to be learned, in a context that is similar to the real world. Thus the general aim of interactive computer-based simulation is to provide the learner with practice of the behaviour he/she will be called upon to exhibit in reality.

Simulation development is expensive so it is usually undertaken when poor performance in "real life" would lead to major problems or other factors such as time, risk and resource availability are involved. In general, simulations are used when:

- the cost of alternate instructional strategies is high (expense),
- the risks involved are considered too high and demonstration of competence in a controlled, relatively risk-free environment is sought (danger/risk),
- it is impossible to study concepts in "real time" (time factors), or
- when a lack of relevant materials exists (material/resources).

Simulations are unique instructional strategies because they are representations of reality that when used in an instructional context are repeatable, consistent, take less time, cost less than most other instructional strategies and are always available.

As a vehicle for the acquisition of knowledge and skills in an active exploratory learning environment, simulations allows for student interaction by the entering answers, directions or decisions and solving problems. During this process, the learner is actively involved in constructing and reconstructing his/her knowledge base. Power is placed into the hands of the student, providing them with the ability to test and communicate their own ideas on how things work. Learning occurs "by doing". The focus within the learning goals thus shifts from recall and reproduction of knowledge to understanding of a domain and transferable knowledge.

Computer simulations are not like general courseware since they do not aim to replace the individual teacher but are designed to provide new learning opportunities. They are ideal when it is impossible to recreate situations that are unacceptable in reality and best utilised when administered to students who have mastered a set of concepts and are ready to apply the acquired knowledge. Because learning through exploration puts a high cognitive demand on learners, inefficient and ineffective learning behaviour may occur in the floundering student. Learners may become involved in making changes randomly instead of purposefully manipulating variable and parameter values, and there is a chance that especially weak learners may derive little benefit from the simulation. Thus for simulations to be effective, they require the presence of an instructor or a computer learning environment to monitor student performance and provide guidance in the use of simulations to challenge existing knowledge. The subject of providing support to learners in exploratory learning environments however, has as yet received little research.

Features and characteristics

Effective and interactive computer-based simulations provide a believable set of events or circumstances, clear student options, a range of progressive and plausible consequences for ongoing student responses and guidance for completion of the scenario.

Simulation based training systems are featured by the following:

- Learners have various experiences of the objective world in imaginary environments and gradually establish mental models inductively. The baseline set of circumstances defining the simulation are presented to the student in the initial scenario. It offers the student sufficient information for him/her to base an informed response and they must choose an appropriate course of action. The student should have a clear expectation of the anticipated consequences of the response he/she made. In some cases, the student may even be asked to submit their own expectation prior to the continuation of the simulation. Used as such, simulations help students build a mental model of part of the world.

- Simulation courseware does not bore the learner since "flying" an aeroplane or diagnosing a simulated patient is certainly more interesting than reading about how to do it from a textbook.

- Learners grasp concepts more easily through visualisation without the need for complex natural language comprehension. Since most people grew up with the television, visual representations are familiar to them. Thus simulations systems used in areas such as plant operations, troubleshooting and science, can be easily related to plausible and realistic scenes encountered in real life. Some well known uses are within the areas of Aircraft navigation - flight simulations; Emergency situations - control panelled interactions to respond to emergencies (as previously described in the introduction to this paper).

The desired conditions of a simulated environment are:

- Quick responses to learner actions or operations
- Simulation models are well integrated into courseware
- Each step of the situation is easily understood
- Simulations designed by exemplar performers - which becomes more important and apparent with the increasing complexity of some systems or environments.

Thus, the use of computer simulations is characterised by the presence of a formalised and manipulable model [1].

- An entity (process, equipment, a system etc.) is formalised into a model and implemented as a computer program. The model itself can range from simple to complex. Students interact and output is inferred or calculated from the implemented model. In some cases, the procedure of entering input and analysing output is as critical as the underlying model (eg. flight simulators).
- Presence of learning goals (ie conceptual or operational knowledge). When the acquisition of knowledge relates to the underlying model then the learning goals are conceptual in nature. Alternatively, the attainment of specific procedures relates to operational knowledge (eg. learning to fly)
- Elicitation of specific learning processes (ie hypothesis and testing). Simulations generally invoke specific learning processes of exploratory learning such as hypothesis generation. The learner can generate his/her own hypotheses and test them within the simulated environment.
- Presence of learner activity (ie manipulating the model). Learner manipulates something in the simulation, eg, setting input variables and parameters, attaching measuring devices, etc. and observes its effects.

Research in computerised simulation

Current educational research indicate that learning to apply knowledge and transfer of knowledge to new situations require more hands-on training - that is learning by doing.

Through approximation, replication or emulation of some task or environment, simulation is one of the best ways to concrete abstract concepts and relations between them and offers good opportunities to facilitate learning processes.

Alessi and Trollip (1985) categorised computer-based simulations into four basic types; physical, procedural, role-play and process. In physical type simulations, a physical object is displayed allowing the student to use and manipulate it rather than read about it in a textbook: for example, a hand-held calculator. A simulation of how to operate it would be more effective than reading about it.

By and large, most simulations are used as vehicles for procedural content. The student acquires knowledge on how to operate a simulated machine rather than how it works: for example, a flight simulator teaches flying procedures rather than how instruments work. Procedural simulations teach a sequence of actions that constitute a procedure: for example, performing a titration experiment, operating a calculator, diagnosing equipment failures, landing a plane, troubleshooting a fuel system.

Within a role-play simulation, the student takes on a role and exhibits a learned set of behaviours that will optimise his/her successful performance. It allows the student to test different approaches to various situations. Many games take on this approach, for example *Where in the world is Carmen San Diego?* Another example or role-playing may include cases such as allowing the student to play the role of a fish which must find food sources and elude its predators. Used as such, it aims to teach problem solving skills. Since there is no single correct way to ensure survival, different number of strategies that increases its chances can be explored safely within a simulation.

In process simulations, students select values of various parameters at beginning and then observes the continuation of a process without intervention. The method usually involves the generation of hypotheses, and testing via observation results: for example genetics or forecasting. Learning occurs by repeating the process a number of times with different starting values and comparing results. Furthermore, simulated processes can be accelerated or slowed down versions of real process (passage of light, population growth). Thus it is easier for the student to conceptualise what is occurring when presented in a time frame which highlights changes taking place.

Eriksson and Reijonen (1990) also categorised simulation into three basic types: games simulations; field simulation; and role-playing simulation. By researching its use and applicability, they found that computerised simulation models dominated over role-playing and games.

Most educational researchers agreed that simulation is one of the best ways to concrete abstract concepts. It is possible to create a very concrete picture of abstract concepts and relations between concepts, to show dynamically how variables change state, what happens in a process and how a process/program functions. It is for this reason that simulations are widely used in training.

Why use simulations in instruction?

Computerised simulations create a 'world' in between reality and some abstract model of it, helping the learner to bridge the gap between reality and the model. The uniqueness of using simulation in instruction lies in its ability to be incorporated within all phases of instruction:

- Presentation of information (tutorials)
- Guiding students in skill and knowledge acquisition (tutorials)
- Providing practice to enhance fluency (drill and practice)
- Assessing learning (tests and assessment)

Table 1: Simulation

	Computerised simulation models	Role play	Games
Complicated organisations	X		X
Prognosis and prediction	X		
Analysis	X		
Control systems	X		
Physical systems	X		
Traffic systems	X		
Planning	X		
Macro economic processes	X		X
Dynamic processes	X		X
Process industry	X		
Training and education	X	X	X
Systems development	X	X	
Use of information systems		X	

There are many reasons for using simulation:

- Simulations are motivating and enhance learning of factual information. It allows for better understanding of processes, improves critical thinking and transferability to other situations.
- OJT (On the Job Training) can be dangerous, expensive and/or time consuming.
- Simulations allow for the possibility of introducing disasters so learners can learn to effectively and efficiently react to them.
- Time scales can be changed to observe processes that would normally proceed too fast or too slow in real life.

Instructional design starts with a situation and tries to define instruction in order to give an answer to that situation. In creating an ISLE (Intelligent Simulation Learning Environment) two main components must be addressed:

The domain:
The basis of simulation is some model of the domain. Models may differ on a variety of dimensions. eg number of parameters, number and type of relations, static vs dynamic (if time is a variable), qualitative vs quantitative relations.

The learner:
Learners possess cognitive and non-cognitive characteristics which are significant when interacting with simulations. Eg. domain knowledge, self control, etc... An ISLE will need to adapt instruction to individual differences and to the knowledge base as it develops during the learning process.

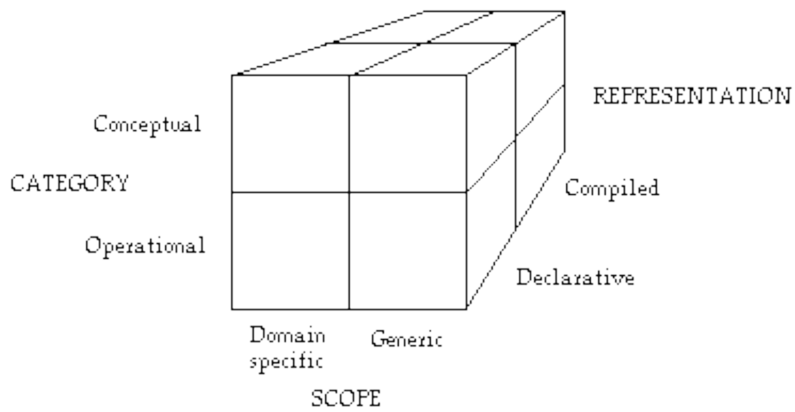
Learning goals and processes

Table 2: A conceptual framework for a componential description of computer simulations in an instructional environment [2]

THEMES	DESIGN COMPONENTS		
	Domain	**Learner Characteristics**	**Instructional strategy**
Models	Domain/simulation models	Mental models Misconceptions	Progressive implementation
Learning goals	Scenarios Experimental frame	Prior knowledge Related skill levels	Immediate feedback for skill learning
Learning processes	Complexity of domain	Scientific skills Self regulation Self confidence	Hints Suggestions Explanations
Learner activity	Handles on the model	Knowledge of exploratory learning environments	Giving constraints on input

Taxonomy of learning goals

Specific learning goals can be classified into basically three categories and can best be seen by the following 3-dimensional matrix:



- Knowledge category - conceptual or operational?
  Conceptual - principles, concepts and facts related to class of system being simulated.
  Operational - sequence of operations/procedures applied to the simulated system.
- Knowledge representation - declarative or compiled?
  Declarative - format that is relatively easy to acquire, report upon, used

in unlimited problem contexts and requires interpretation in order to use it in a task.
Compiled - format obtained after using knowledge in a problem solving context and makes the knowledge hard to report upon and restrictive in its potential use in problem contexts.

- Knowledge scope - domain-specific or generic?
  Domain-specific - specific to simulation domain at hand eg troubleshooting a particular piece of equipment.
  Generic - extendible to other domains eg general troubleshooting techniques.

For example, a simulation to train nuclear power station operators to automatically react to cooling system failure relates to learning goals addresses areas of operational, domain specific and complied knowledge. However, most simulations do involve more than one learning goal, ie partly domain-specific and partly generic, or partly declarative and partly compiled and thus there may be no clear line of distinction between learning goals with respect to performance from simulation learning.

Learning processes

Since learning within simulated environments is seen as exploration-based, understanding the learning processes involved leads to a better comprehension of why computer simulations are used in instructional contexts. The learning processes themselves are defined as the learner's cognitive transactions, transforming information into knowledge. Students formulate and discover for themselves rules of defined principles, preferred procedures, or higher order skills. This active reconstruction encourages the meaningful incorporation of information into the learner's cognitive structure. Problem solving, discovery learning and inductive learning are seen to constitute a general framework for the description of learning processes that are invoked within exploratory environments.

- When learning with a computer simulation, the student is involved in a *problem solving* process which is purpose oriented. The student is directed to achieve several learning goals by performing a sequence of actions to turn an initial state to a goal state.
- *Discovery learning* allows for and encourages active experimentation and exploration. The learner can discover important concepts and principles, find solutions to problems and so on by not only discovering new information or entities but also by reclassifying and relating known information. According to Ausubel, the essential feature of this type of learning process is that the content of what is to be learned is not given to the student but must be discovered before it can be meaningfully incorporated into the learners cognitive structure.

- *Inductive learning* is where the learner formulates rules, based on forming and evaluating hypotheses. This process involves generalising, transforming, correcting and refining knowledge representations.

Learning activity

Learning activity refers to the physical manipulations executed by the learner within the simulation:

- Setting environmental qualities which remain constant for the duration of the simulation: for example, setting the temperature required for a scientific experiment.

- Defining the initial conditions which can change during the simulation: for example, economics/budgeting forecasting - the amount of money a person owns can be defined at the start but may change in time.

- Deciding the next step to take, which becomes crucial in procedural and operational simulations.

- Controlling the pace and direction of the simulation to investigate very slow or fast processes. It may also be possible to reverse the direction, (going back in time).

In summary, it is assumed that learning with computer simulations allows for attaining certain learning goals with models of domains by encouraging the learner to invoke specific learning processes in performing certain learner activities.

Value of computer-based simulations

Bessemer and Kolosh (1992) examined the value of using computer-based simulation systems for training students to use higher order cognitive constructs. They believed that the effectiveness of using such an instructional system lies in providing the students with realistic and safe "learn-by-doing" opportunities.

Designed to allow learners practice skills employed in real life situations. without the risk of injury or damage to equipment, Reigeluth and Schwartz. (1989) and Breuer and Kummer (1990) argued that computer-based simulations helped students master cognitive processing skills by allowing them to apply concepts within a realistic environment.

Simulation systems have been used to provide effective realistic role playing opportunities for practicing and understanding the procedures involved in many areas, including:

- operating a space capsule;
- flying a plane;
- managing a nuclear reactor;
- repairing a missile system; and
- reacting to industrial emergencies.

Once skills/knowledge are acquired they are usually well transferred when applied to real life situations. Students who use simulations, manipulate variables and so on would be better prepared to perform in real situations than those students who rely on other instructional media, such as text, which can only provide information and hints on how to do something.

The emerging generation of interactive computer based simulations (including virtual reality) has been designed with the underlying assumption that **students learn best by doing.** This principle has been widely adopted by military training programs. "The Interservice Procedures for Instructional Systems Development (ISD), for example, had mandated that Army training be designed to provide students with practical exercises under realistic conditions (US Army Training and Doctrine Command, 1975, 1988)" [3].

Bessemer and Kolosh (1992) studied the effectiveness of using SIMNET (Simulation Networking), a simulated battlefield environment consisting of combat vehicle simulators with simulated combat support, to help train prospective armour platoon leaders in applying the principles of armour platoon tactics. The simulation was conducted under constraints similar to those affecting actual battlefield conditions. Investigations and evaluations of student performance in field exercises were conducted prior to and after the introduction of SIMNET into the Armour Officer Basic classes in 1988. Results showed that the average value for student performance ratings were significantly higher than those students who did not receive SIMNET training. Thus Bessemer and Kolosh (1992) claimed "interactive computer-based simulation systems that provide students with appropriate role playing activities can train them to acquire the conditional knowledge necessary for successful performance in dynamic vocational environments" [4].

Application of computer-based simulations

In using simulations to address the cognitive domain, specific problem solving, planning and decision making allows the learner to adopt the role of decision maker or planner. Benefit is the 'safety' factor where errors in judgement will not incur dire consequences that would occur in reality. Also, the compression of time allows the results of decisions (which might take months to show in real life) to be examined.

Within the psychomotor domain, the elimination of on job dangers and the reduced need for expensive equipment increases training effectiveness: simulated space flight training would certainly be more cost-effective and safer to use than real systems.

Simulation is also used for experiments which cannot be performed in a laboratory either due to its microscopic nature or the time taken to observe certain element characteristics, like splitting of the atom, chemical or genetic engineering. The simulation could be slowed down to allow careful study of the critical aspects of the environment or the object being simulated.

Another application may be in the operations of petroleum refineries where the control of such processes becomes highly sensitive, requiring a high level of abstract concepts and capacity to assimilate an enormous quantity of information. The simulator aims to provide an efficient and economical means of training the operator to face possible incidents or the problems of balancing economy of energy use and optimal operation.
The simulation would pose problems which the operator would be expected to solve or regulate. When a problem is introduced into the simulated environment (either by the instructor or the computer learning environment), the learner is expected to either request more information or to act on existing information.

Used in training, simulations provide an environment conductive to learning by reducing distractions that may interfere with the learning task. For example, a novice training pilot would be rather apprehensive if he/she had to operate instrument controls, listen to traffic control messages and monitor other nearby aircraft. More attention is required and detracts from the real purpose if the objective is to control the plane. Within a simulation, events can be isolated and re-introduced when the student is better prepared to cope with additional events and distractions.

Conclusion

Interactive computer-based simulations "permit the study of processes, procedures, and phenomena that either cannot be taught under any circumstances or cannot be easily taught using traditional methods" [5]. As an alternative to high-cost or high-risk learning, they are designed not to teach directly but to demonstrate the effects to students. However, students need sufficient prior knowledge of the domain, otherwise attention will not be focused on relevant relationships preventing effective integration of the material into existing concepts. Thus, criterion knowledge used to make effective judgements must be taught prior to the simulation and guidance/support provided to give feedback on performance during or post simulation.

Since most people grew up with the television, they are familiar with visual presentations on screen. Allowing them to actively participate and control the parameters is an ability which cannot be achieved by traditional written text methods of the past. By providing a simulated environment, behaviour that is expected in reality can be performed in a safe, risk-free and controlled environment. As an instructional strategy, used effectively to improve learner performance, the ability of simulations to concrete concepts can be best expressed by the following:

I look and I see
I listen and I hear
I do and I understand.

Notes

1. Computer modelling is closely related to computer simulation, however, unlike instructor designed simulation, learners have the ability to vary the properties of the model.
2. Adapted from T. de Jong (1991), *Education and Computing.*
3. Bessemer and Kolosh (1992), p111
4. ibid, p113.
5. Hannafin and Peck (1988), p153.

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Please cite as: Gatto, D. (1993). The use of interactive computer simulations in training. *Australian Journal of Educational Technology*, 9(2), 144-156. http://www.ascilite.org.au/ajet/ajet9/gatto.html