COMPUTER SIMULATIONS IN SCIENCE EDUCATION: Implications for Distance Education

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ABSTRACT

This paper is a review of the literature about the use of computer simulations in science education. This review examines the types and good examples of computer simulations. The literature review indicated that although computer simulations cannot replace science classroom and laboratory activities completely, they offer various advantages both for classroom and distance education. This paper consists of four parts. The first part describes computer simulations; the second part reviews the benefits in science education; the third part looks for the relation with science process skills; and the last part makes connections with the distance education.

The literature suggests that the success of computer simulations use in science education depends on how they incorporated into curriculum and how teacher use it. The most appropriate use of computer simulations seems that use them for a supplementary tools for classroom instruction and laboratory. Multimedia supported, highly interactive, collaborative computer simulations appealing growing interest because of their potentials to supplement constructivist learning. They offer inquiry environments and cognitive tools to scaffold learning and apply problem-solving skills. Computer simulations are good tools to improve students' hypothesis construction, graphic interpretation and prediction skills. The literature review also implied that computer simulations have potential for distance education laboratories. Yet this area is elusive and needs to be researched further.

Keywords: Distance education; computer; simulation; science; laboratory; constructivism.

INTRODUCTION

In the United States, education has been challenged with the promise of educating all children. Fulfilling this promise may require more innovative use of computers. In fact, computers have been used in teaching and learning for several years. Teachers have been using them for many purposes beyond word processing. One type of computer application is simulations. Although the use of computer technologies in the schools is still debated among scholars (such as Larry Cuban, 1997) computers can play important roles in the classroom and laboratory science instruction (e.g., Lazarowitz and Huppert, 1993; Akpan and Andre, 1999).

Computer simulations give students the opportunity to observe a real world experience and interact with it. Simulations are useful for simulating labs that are impractical, expensive, impossible, or too dangerous to run (Strauss and Kinzie, 1994). Simulations can contribute to conceptual change (Zietsman, 1986; Stieff, 2003); provide open-ended experiences for students (Sadler et al. 1999); provide tools for scientific inquiry (Mintz, 1993; White and Frederiksen, 2000; Windschitl, 2000; Dwyer & Lopez, 2001) and problem solving experiences (Woodward et al., 1988; Howse, 1998). Computer simulations also have potentials for distance education (Lara & Alfonseca, 200; McIsaac and Gunawardena, 1996).

The main purpose of this paper is to review the use of computer simulations in science education. The main audiences for this study are instructional designers and curriculum leaders who seek a way to enhance teaching and learning with technology in both the classroom and distance. The second purpose is to review potential use and benefits of computer simulations in science laboratories distance education.

COMPUTER SIMULATIONS IN SCIENCE EDUCATION

Thompson, Simonson and Hargrave (1996) defined simulation as a representation or model of an event, object, or some phenomenon. In science education a computer simulation according to Akpan and Andre (1999) is the use of the computer to simulate dynamic systems of objects in a real or imagined world.

Computer simulations take many different forms from 2 or 3-dimensional simple shapes to highly interactive, laboratory experiments and inquiry environments. Figure-1 shows a 2-dimensional graphical representation of weather dynamics over a mountain and a 3-dimensional DNA structure. Figure-2 shows screen captures of two computer simulation. First, the Exploring the Nardoo" enables students explore dynamics of a river. Second, BioWorld enables students examine the body structure and systems. Both of them allow interactivity and collaboration.

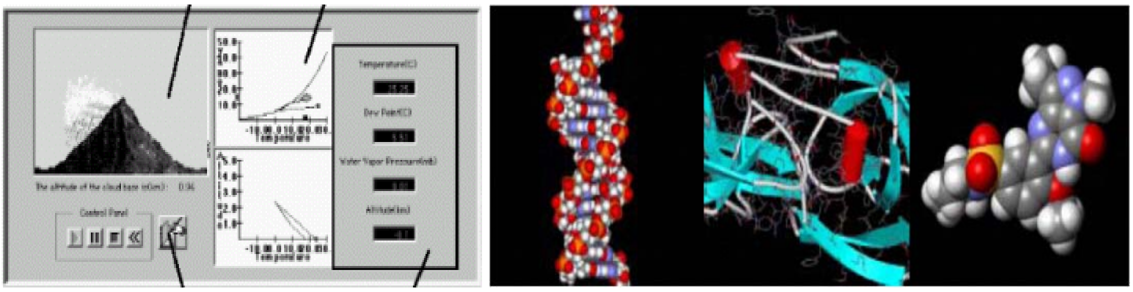

Figure: 1
3D DNA structure and 2D mountain simulation
(MtnSim: Available at http://www.iastate.edu/~abc/java/mtnsim/mtnsim.html)

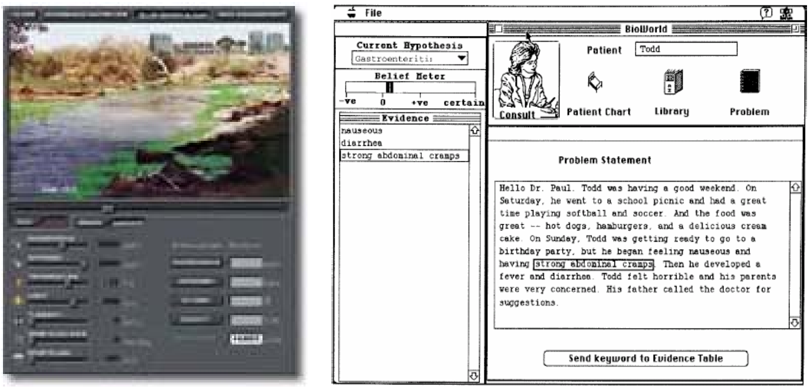

Figure: 2
Exploring the Nardoo and Bioworld simulations

different types of computer simulations defined in the literature permit instructional designers to use them to accomplish instructional objectives either behavioral or cognitive. Alassi and Trollip (1991) describe simulations in educational context that

> "A simulation is a powerful technique that teaches about some aspect of the world by imitating or replicating it. Students are not only motivated by simulations, but learn by interacting with them in a manner similar to the way

they would react in real situations. In almost every instance, a simulation also simplifies reality by omitting or changing details. In this simplified world, the student solves problems, learns procedures, comes to understand the characteristics of phenomena and how to control them, or learns what actions to take in different situations."

In their description, Alessi and Trollip emphasized on that a simulation simplifies reality by omitting or changing detail. This point of view goes back to Gagné (1962); he claimed "simulations as an instructional tool eliminate undesirable components of real situations in order to reach predetermined learning outcomes". According to Grabe and Grabe (1996) simplification allows learners focus on critical information or skills and make learning easier. This perspective for the use of simulations is very appropriate for accomplishing simplified behavioral and cognitive tasks.

On the other hand, scholars from constructivist pedagogy describe educational simulations as a simulated real life scenario displayed on the computer (Wilson and Jonassen, 1993), in which the student plays an authentic role carrying out complex tasks (Harper, 2000). From this point of view, simulations should reflect the complexity of the real life so that students struggle and learn higher order cognitive skills such as inquiry, which is viewed as essential for science learning (National Science Education Standards, 1996). These simulations take learners in such an environment that they conduct several integrated tasks so that they learn complex skills in authentic problems or inquiries such as the Nardoo, and BioWorld (Lajoie et al. 2001).

"Exploring the Nardoo is a CD-Rom package modeling an imaginary river system. Students investigate the river system or solve a set problem, including how coal mining, forestry or urban development affect the river system, the life along with it, and the people living along its length" (Exploring the Nardoo). The simulation gives twelve tools to use for water analysis. To solve identified problems, students work individually and collectively. For this they encounter integrated activities such as Discussing situations, surveying for problems and hypothesizing for solutions, identifying data sources, collecting data, testing hypothesis and presenting findings (Harper 2000).

"BioWorld is a computer-learning environment designed for high school biology students. BioWorlds complements the biology curriculum by providing a hospital simulation where students can apply what they have learned about body systems to problems where they can reason about diseases. Students work collaboratively at collecting evidence to confirm or refute their hypotheses as they attempt to solve BioWorld cases" (Lajoie et al. 2001). This simulation environment takes students into such an environment that consists of authentic real life cases so that learners can conduct meaningful inquiries with the support of multimedia. Similar to Exploring to Nardoo, BioWorld provide students with cognitive tools to scaffold learning, which is one of the fundamental features of constructivist learning environments (Jonassen, 1995).

Thomas and Hooper (1991) classified simulations in four categories. Experiencing simulations are used to set the cognitive or affective stage for future learning. Use of these programs precedes the formal presentation of the material to be learned. BioLab-Frog (Akpan and Andre, 1999) is a good sample for this type of simulations. BioLab-Frog is a software package simulating an actual frog dissection. "As the students view and remove organs, the software displays added information about each item. It also uses QuickTime movies and microscopic pictures to illustrate functions that are normally hidden from view. It reinforces learning with a review quiz after presenting each system. In the quiz, the participants match the function to the structure (Akpan and Andre, 1999)." However they reported that although using the simulation before the actual experiment is beneficial there is no clear evidence

that computer simulations change students' attitudes. MtnSim (Hsu and Thomas, 2002) is another sample for experimenting simulations in which students analyze the effects of a mountain lifting the air on the windward side and lowering the air on the leeward side for different characteristics of the air.

Informing simulations are used to transmit information to the student. However Thomas and Hooper (1991) reported that simulations are not an appropriate way for knowledge transfer when they used without the support of teacher. Informing simulations is more appropriate when incorporated in a supporting environment such as regular classroom or laboratory work.

> **"Reinforcing simulations are for strengthen specific learning objectives. The most common format for reinforcing simulation is drill and practice, in which a sequence of stored or generated exercises is presented for the student to complete. These simulations can be designed to adjust to the student's knowledge level and to track the student's progress (Thomas and Hooper, 1991)".**

"The use of integrating simulations seems to be most prevalent for the acquisition of diagnostic skills. In these studies, the students first learned the required factual information and principles and then used the simulations to relate and apply that knowledge (Thomas and Hooper, 1991)". CATLAB is a good example for this type of simulations. It is a genetics simulation program that utilizes cats. Like most other integrating simulations (e.g., Exploring the Nardoo and BioWorld) students need to have some basic understanding of genetics before using this program. "There are three basic types of open-ended problems in the program. One set of exercises presents hypotheses the students test by breeding cats. The majority of the exercises require students to explain observed results that are either given by the program or are self-generated. Finally, there are two exercises that are highly structured and walk the students through hypothesis testing and data analysis (Hays and Vázquez, 2002)".

Gredler (1996) distinguishes between two types of simulations: symbolic and experiential. According to them, in symbolic simulations, the student is not an active participant of the program environment. Although students may execute any of several tasks such as predicting population trends in a demography simulation, the student remains external to the evolving events. On the other hand, experiential simulations immerse the students in a complex, changing environment in which the student is an active components. They allow students to execute multidimensional problem-solving strategies as part of their role in the program. They also provide learners with opportunities to develop their cognitive strategies by learning to organize and manage their own thinking and learning. Experiential simulations may be cooperative or individualized exercises due to the nature of the participant's roles and the types of decisions and interactions in the exercise.

Gredler (1996) states that the essential components of an experiential simulation are a scenario of a complex task or problem that unfolds in part response to learner actions, a serious role taken by the learner in which he or she executes the responsibilities of the position, multiple plausible paths through the experience, and learner control of decision making. "The Shell Island Dilemma" is good sample for this type of simulations. It is an inquiry simulation that "students investigate the issues concerning the fate of the Shell Island Resort and then debate the future of this and other oceanfront structures threatened by coastal erosion. As students engage in the investigation, they identify the social, political, and scientific issues with which different stakeholders must deal. Students place themselves into the role of one of the stakeholders. Questions are used throughout the simulation to focus students' inquiry during their exploration. After being introduced to the problem with a video clip, students are to select their stakeholder role including the Shell Island

Resort homeowners, the Wrightsville Beach town manager, North Carolina Coastal Resources Commission members, Coastal engineers, Coastal scientists, and members of the environmental advocacy organization, North Carolina Coastal Federation" (The Shell Island Dilemma - Educator's Guide).

De Jong and Van Jooling (1998) divide computer simulations into to main categories: simulations containing a conceptual model, and those based on an operational model. "Conceptual models hold principles, concepts, and facts related to the systems being simulated. Operational models include sequences of cognitive and non-cognitive operations procedures that can be applied to the simulated systems. Operational models are generally used for experiential learning; in a discovery learning context mainly find conceptual simulations. Furthermore in their article, 1991, van Joolingen and de Jong further included a wide range of model types such as qualitative vs. quantitative models, continuous vs. discrete and static vs. dynamic models.

Computer simulations reflect instructive or constructive pedagogies. Those simulations that include learners as an external player on the provided conditions are instructive in nature (e.g., BioLab-Frog, MtnSim). Instructive simulations may include information simulations, reinforcing simulations, experimenting simulations, symbolic simulations, and operational simulations. On the other hand, Constructive simulations provide learners with a contextual environment in which they take place and play roles (e.g., Exploring the Nardoo, Bioworld) that may include integrated simulations, experiential simulations, and conceptual simulations may reflect constructive simulations. The Table-1 displays the connection between types of simulations described in the literature and two main pedagogies, instructive and constructive. The types and examples of computer simulations analyzed so far. Next section will review the use of computer simulations in science education.

Table: 1
Types of simulations and related pedagogies

	Instructive	Constructive
Thomas & Hooper	Informing simulations Reinforcing simulations Experiencing simulations	Integrating simulations
Gredler	Symbolic simulations	Experiential simulations
De Jong & Van Jooling	Operational simulations	Conceptual simulations

USE OF COMPUTER SIMULATIONS IN SCIENCE EDUCATION

Computer simulated instruction gives students the opportunity to observe a real world experience and interact with it. In science classrooms, simulation can play an important role in creating virtual experiments and inquiry. Problem based simulations allow students to monitor experiments, test new models and improve their intuitive understanding of complex phenomena (Alessi and Trollip, 1985). Simulations are also potentially useful for simulating labs that are impractical, expensive, impossible, or too dangerous to run (Strauss and Kinzie, 1994). Simulations can contribute to conceptual change (Windschitl, 1995); provide open-ended experiences for students (Sadler et al. 1999); provide tools for scientific inquiry (Mintz, 1993; White and Frederiksen, 2000; Windschitl, 2000; Dwyer & Lopez, 2001) and problem solving experiences (Woodward et al., 1988; Howse, 1998).

An appropriate way for simulations in science education is to use them as a supplementary material (McKinney, 1997). Kennepohl (2001) examined the benefits of computer simulations in a first-year general chemistry course. He found that the combination of simulations and laboratory offers advantages in time so that the laboratory portion can be reduced in length and students using the simulations have a slightly better knowledge of the practical aspects directly related to laboratory work.

On the other hand in some situations simulations are the only tools to use like experimenting for dangerous or long-term situations. According to Mintz (1993) one of the most promising computer applications in science instruction is the use of simulations for teaching material, which cannot be taught by conventional laboratory experimentation But can a simulation be as effective as a conventional laboratory or replace it? The answer would be that it depends on the concept or the situation. For example Choi & Gennaro (1987) compared the effectiveness of computer-simulated experiences with hands-on laboratory experiences for teaching the concept of volume displacement of junior high school students. They found that computer simulated experiences were as effective as hands-on laboratory experiences. This suggest that it may be possible to use a computer-simulated experiment in place of a laboratory experience in the teaching of some concepts such as the volume displacement and obtain comparable results. This may suggest that computer simulations may be used to replace those laboratory activities that require cognitive interactions with the content rather than psychomotor interactions so that they not require much physical (e.g., taste, smell, touch) interactions.

Simulations may be offer tools for scaffolding gender differences in instructional settings. For example Choi & Gennaro (1987) found that males, having had hands–on laboratory experiences, performed better on the posttest than females having had hands–on laboratory experiences while there were no significant differences in performance when comparing males with females using the computer simulation in the learning of displacement concept. Yet they didn't conclude on what might cause the difference in performances between males and females with hand-on experiments and what aspects of the simulation might facilitate the gender biases in laboratory materials. There should be further research to confirm their findings. However, according to them, purpose driven simulations can be appropriate tools to eliminate some learning deficiencies. For instance simulations may be used to scaffold learning of those whose ability of imagining relatively low that is critical to understand the dynamics of systems.

Science process skills

Simulations can activate science process skills of students, which are the basic skills for scientific inquiry (Roth and Roychoudhury, 1993). These skills are classified in two main groups: basic science process skills and integrated science process skills. Padilla (1990) listed basic science process skills as observing, inferring, measuring, communicating, classifying, and predicting. He listed integrated science process skills as controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting, and formulating models.

Lazarowitz and Huppert (1993) examined computer simulations in promoting science process skills of 10th grade biology. Their findings indicated that computer simulation can enable students to use the skills of graph communication, interpreting data, and controlling variables in simulated experiments, and helped them master these skills.

Mintz (1993) examined computer simulations as an inquiry tool. Inquiry is fundamental for science learning (National Science Education Standards, 1996). Inquiry procedure included positing hypotheses, conducting experiments, observing and recording data, drawing conclusions. They concluded that computer simulation can expand and improve classroom work. According to their findings, simulations as

an inquiry tool improve motivation and interest. However a Hawthorn effect may be on motivation of students to the computer simulation. It should be well understood that students interested in the topic in a simulated environment not the simulation itself.

Lavoie & Good (1988) examined computer simulations in the use of prediction skills in a biological computer simulation that the computer-simulation program proved to be an effective tool. In contrast to findings of Mintz (1993) and Lazarowitz and Huppert (1993) they find that the use of computer simulations probably not a major factor affecting subjects' motivation. In their study many of the subjects had worked extensively with computers previously. This decreased the novelty, which otherwise may have acted to increase interest.

Simulations in distance laboratories

Simulations can be used in distance education (Lara & Alfonseca, 200; McIsaac and Gunawardena, 1996). Software companies offer online simulations. Educators who are creating distance courses may be faced with difficulty to include the hands-on lab component. They must have the student come to the laboratory or provide the student with laboratory materials to perform at home. Computer simulations may be a way for distance laboratories. They are not just valuable environments for distance access but also offer pedagogic benefits for science laboratories. According to Hofstein and Lunetta (2003) "the laboratory learning environment warrants a radical shift from teacher-directed learning to "purposeful-inquiry" that is more student-directed". Computer simulations are good tools for individual learning. Distance labs are not restricted to synchronized attendance by instructors and students; they have the potential to provide constant access whenever needed by students (Forinash and Wisman, 2001).

Forinash and Wisman (2001) described some benefits of distance science laboratories. According to them safety, which is a one of concerns of science laboratories are diminished in distance labs.

Computer simulations can also transcend the restrictions of time and space, allowing experiments that monitor geographically distant phenomena such as weather and seismographic data. Because students have greater access to experimental equipment, fewer lab stations are needed, thereby mitigating the costs associated with purchasing and maintaining lab equipment.

Slotta (2002) defined four key elements of inquiry curriculum that may benefit from computer simulations: make science accessible, make thinking visible, help students learn from each other, and help students develop autonomous learning.

On the other hand Forinash and Wisman (2001) suggested key impediments to the growth of distance labs as the absence of an educational model for distance science laboratories, the lack of delivery technology standards for instrument hardware and software, and the considerable technical difficulty and expense of development.

From their experience, Forinash and Wisman (2001) have identified three key requirements for a distance laboratory. Students must have enough control of lab equipment to start and stop an experiment and make appropriate adjustments. The experiment should be no more difficult to conduct than with the equipment physically present. Students need appropriate feedback.

Online simulations may be appropriate solutions for laboratories in distance education. However, the literature review indicated that although there has been an abundance of research on the use of computer simulations and science labs at schools, there is relatively little on online science labs and their use in distance learning.

Table: 2 grasped samples from the literature, which is included within this review. The main criteria for the selection of sample were their research focus rather conceptual because the role of computer simulations in science education especially for laboratory activities needs to be approved research findings. Second criteria were to cover a period to see the trend in research. It can be seen that recently, researchers have been focusing on the use of computer simulations in distance education especially for online.

One research conducted by Kennephol (2001) who examined computer simulations employing video images incorporated into the laboratory component of an existing first-year university chemistry course as part of a pilot study. He surveyed about students' experience and their performance in the distance course and also tracked and compared with students who did not do the simulations.

He found no difference in overall course performance between students completed in-laboratory work in a shorter period and showed a slightly higher performance in the practical laboratory component.

Table: 2
Literature on computer simulations in science education

Year	Researchers	Concern
1981	Lunetta	Science education
1987	Choi & Gennaro	Volume displacement
1988	Lavoie & Good	Prediction skills
1990	Stein, Nachmias & Friedler	Compare simulation and conventional lab.
1992	Farynaiarz & Lockwood	Problem solving
1993	Mintz	Inquiry
1994	Strauss & Kinzie	Compare simulation and conventional lab.
1995	Rieber & Kini	For inductive learning
1996	Thompson et al.	Science education
1997	Coleman	Science experiments
1998	Windschitl	Science inquiry skills
1999	Akpan& Andre	Supplement laboratory
2000	Muth & Guzman	For distance education
2000	Winer et al.	Science laboratory on the Internet
2001	Forinash & Wisman	Distance science education laboratories
2001	Kennepohl	Supplement distance laboratory
2002	Hsu & Thomas	Web-aided instructional simulations

Winner et al. (2000) examined the distributed collaborative science-learning laboratory (DCSLL) as the electrical circuit simulator. DCSLL appears to be a practical way to provide authentic lab experiences and reduce student isolation while respecting the fundamental constraints of distance education. According to them, careful attention must be paid to design and management issues raised by this new instructional approach and increased technical complexity of the learning environment must be taken into account when designing the instructional activities.

Lara and Alfonseca (2001) described the construction of virtual reality simulations for distance education through the internet. Their online simulations offered "other possibilities of interaction such as setting hyperlinks in the simulation objects, which can be used to explain the role of the object in the simulation".

Linser & Naidu (1999) examined the experience of using a web-based simulation in the political science. They concluded that a simulation designed for collaborative learning in context will not only motivate and encourage students to learn, but as a result, will also be a more effective tool in teaching and learning than traditional means used in the discipline.

CONCLUSION

The literature review suggests that computers may play important roles in the classroom and laboratory science instruction in either the classroom or distance. They can be used with instructive or constructive pedagogy. Computer simulations give students the opportunity to observe a real world experience and interact with it. Computer simulations are potentially useful for simulating labs that are impractical, expensive, impossible, or too dangerous to run. Simulations can contribute to conceptual change, provide open-ended experiences, and provide tools for scientific inquiry and problem solving. Computer simulations also have potentials for distance education.

The literature implied that computer simulations are good supplementary tools for classroom instruction and science laboratories. Multimedia supported, highly interactive, collaborative computer simulations appealing growing interest because of their potentials to supplement constructivist learning. They offer inquiry environments and cognitive tools to scaffold learning and apply problem-solving skills.

The literature suggests that the success of computer simulations use in science education depends on how they incorporated into curriculum and how teacher use it. The most appropriate use of computer simulations seems that use them for a supplementary tools for classroom instruction and laboratory. Computer simulations are good tools to improve students' hypothesis construction, graphic interpretation and prediction skills. The literature review also implied that computer simulations have potential for distance education laboratories. Yet this area is elusive and needs to be researched further.

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