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ABSTRACT

This study involved students using simulation software in all phases of the learning cycle. Research on the use of simulations in science education has shown that the simulations can be used effectively in preinstructional and exploratory activities. Preinstructional and exploratory activities elicit and challenge students' alternative conceptions. Having set the context for formal instruction, simulations then can be used to learn new concepts in the invention phase of the learning cycle. The purpose of this case study was to develop, administer, and collect student data on learning cycle lessons that use simulations in all phases of the cycle. Fourteen upper elementary and 17 middle school science students were observed, along with their teacher, using simulations as they engaged in learning cycle lessons revolving around river ecosystems. It was found that with the specific guidance in simulations such as "Exploring the Nardoo," students perform better. Simulations can be used again to apply newly learned concepts in different contexts in the expansion phase of the learning cycle. An example of a learning cycle using simulations in all phases is appended. (Contains 36 references.) (MES)

Simulations in the Learning Cycle: A Case Study Involving "Exploring the Nardoo"

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Simulations in the Learning Cycle: A Case Study Involving *Exploring the Nardoo*

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Introduction

This study involved students using simulation software in all phases of the learning cycle. Research on the use of simulations in science education has shown that the simulations can be used effectively in preinstructional (Hargrave & Kenton, 2000; Gokhale, 1996) and exploratory activities (de Jong & van Joolingen, 1998). Preinstructional and exploratory activities elicit and challenge students' alternative conceptions. Having set the context for formal instruction, simulations then can be used to learn new concepts in the invention phase of the learning cycle. With the specific guidance in simulations such as *Exploring the Nardoo* (Harper & Hedberg, 1996, 1997), students perform better (Lee, 1999). Simulations can be used again to apply newly learned concepts in different contexts in the expansion phase of the learning cycle.

Background

Simulations in science education

Simulations have aided scientists in extending their experiences to otherwise unobservable phenomena (Richards, Barowy, & Levin, 1992; Snir, Smith, & Grosslight, 1995; Coleman, 1997; Jonassen, 2000). Simulations can perform a similar function for students in restrictive classroom environments by providing science experiences they would otherwise be unable to have (Roberts, Blakeslee, & Barowy, 1996). Simulations also serve to "bridge the gap between complex mathematical theories and experience. . . They create new visual representations of phenomena that aid in building scientific intuitions" (p. 69; see also Jackson, 1997; Lee, 1999).

The use of simulations that represent scientific models can help prepare students for building their own models. According to Gabel (1999), simulations are especially useful for scientific models that "are difficult or impossible to observe, or are so complex that they are difficult to study in the laboratory. . . Use of simulations tends to result in increased achievement on complex and difficult concepts in less time than conventional instruction" (p. 163; see also Eylon, B-S, Ronen, M., & Ganiel, U., 1996; Windschitl & Andre, 1998; Härtel, 2000).

Reports on the effects with simulations on student learning have varied widely (de Jong & van Joolingen, 1998; Windschitl & Andre, 1998; de Jong, Martin, Zamarro, Esquembre, Swaak, & van Joolingen, 1999; Lee, 1999), making generalizations difficult. Some studies show that inadequate teaching strategies inhibit learning with simulations (Roberts et al., 1996; Jackson, 1997; Windschitl & Andre, 1998). Roberts et al. (1996) study, as well as others (de Jong & van

Joolingen, 1998; Lee, 1999), indicate a need for better skill preparation and guidance of learners. Roberts et al. claim that students perform best when "shown the way and then left to learn by doing" (p. 48), which the researchers say is similar to Collins' (1990) cognitive apprenticeship. Students first need to acquire skills in information appraisal, selection, organization, structuring, and communication of ideas (Harper & Hedberg, 1997).

Hargrave and Kenton (2000) suggest that the variety of effects observed with simulations may result from the variety of definitions for simulations, and they provide a comprehensive definition derived from the research literature (see conclusion). De Jong and van Joolingen (1998) provide a more concise definition: "A computer simulation is a program that contains a model of a system (natural or artificial; e.g., equipment) or a process" (p. 180). In a metaanalysis of instructional simulations, Lee (1999) reports that using different instructional modes of simulations (presentation and practice) is one reason for conflicting results. Lee also describes differences in the nature of simulations, which can be either "pure" or "hybrid," with the latter incorporating both presentation and practice modes. Overall, Lee claims that students perform better when hybrid simulations are used and when provided with specific guidance.

Exploring the Nardoo and constructivism

In addition to the above considerations, the simulation software used in this study was developed within a cognitive constructivist frameworks under which "learning involves the construction of meanings by the learner from what is said or demonstrated or experienced" (Harper & Hedberg, 1997, p. 4) and in which "[t]he role of the teacher is one of facilitating the development of understanding by selecting appropriate experiences and then allowing the students to reflect on those experiences." The developers of *Exploring the Nardoo* had these considerations in mind when developing the program. Attending to a new technology in constructivism, the developers focused on learning that is mediated by tools and signs which implies that "the tools (technology) and signs (semiotic tools) we use change the form, structure, and character of activities and thus our knowledge" (Harper & Hedberg, 1997, p. 4).

Cognitive tools help learners to organize, restructure, and represent their knowledge (Harper & Hedberg, 1997). The developers of *Exploring the Nardoo* incorporated a series of cognitive and, they hoped, metacognitive tools in their design process. They relied upon key principles of cognitive tools research as summarized by Jonassen and Reeves (1996) for multimedia design:

- Cognitive tools will have their greatest effectiveness when they are applied to constructivist learning environments.
- Cognitive tools empower learners to design their own representations of knowledge rather than absorbing knowledge representations preconceived by others.
- Ideally, tasks or problems for the application of cognitive tools should be situated in realistic contexts with results that are personally meaningful for learners (p. 698, as reported in Harper & Hedberg, 1997).

While software, especially simulations, developed under constructivist frameworks tend to favor group interactions (Linser & Naidu, 1999), individuals who display the motivation and metacognitive skills of self-regulated learners can gain maximum benefit from the software without peer support (Harper & Hedberg, 1997; Gabel, 1999; Jonassen, 2000). Groups, however, can provide forums for the discussion of ideas and suggestions, problem-solving strategies, immediate feedback, and so on. The developers also considered a problem-based learning approach in which students learn more from being given a problem that they must solve rather than from being given instructions on how to do something. Students are presented with an ill-structured problem prior to formal instruction (Harper & Hedberg, 1997). They then must themselves identify and use the knowledge required to solve the problem.

In *Exploring the Nardoo*, an imaginary river ecosystem provides students with opportunities to explore environmental issues while applying science concepts from the areas of biology, chemistry, physics, as well as other subjects areas, such as geography, social science, language, and media studies. Students can explore interactions among living organisms and the physical environment, which focus on human impact at both a macro and micro level (Jonassen, Peck, & Wilson, 1999). Small groups of students can interact and apply problem solving, measuring, and communication skills to investigate issues and report their findings. Their efforts are facilitated by the program's Water Research Centre where three specialists introduce investigations and make suggestions for accessing media, using data-collection tools, and running simulations. Many of the resources are accessed through a personal digital assistant that has been incorporated into the program, providing a problem-solving situation "that enables students to actively manipulate a complex environment, seek information, and conduct investigations in order to construct their own knowledge about ecological issues" (p. 99). The classroom edition includes many activities (in print), divided by subject areas, that help integrate the CD resources into the science curriculum (Rapose, Cesaro, Poirier, Collins, Toppi, & Plante, 1997).

The program allows students to take readings in the simulated environmental sites and answer their "what if" questions by inputting their data, running the embedded simulators, and observing the changes (Harper & Hedberg, 1997). The students can monitor changes in variables as the simulators run, exploring the relationships among the variables in the model systems. "The ability to directly compare input data with output data in various forms simultaneously is a powerful feature of each of these simulators and helps the user in making connections and associations and forming an understanding of the interrelationships between 'cause and effect'" (p. 13). An embedded simulator that was used in this study (blue-green algae) incorporates a real-time graphing feature that allows students to "see" how relationships among variables change with time (Coleman, 1997).

Harper and Hedberg (1997) claim that *Exploring the Nardoo* and related programs were developed to allow students to participate in communities of practice through immersion in authentic activities (see also Harper, Hedberg, Wright, & Corderoy, 1995; Aikenhead, G. S., n. d.). The program's data collection facilities allow information collection from a range of media sources, and the simulations allow students to ask questions and investigate answers to those questions. The problem-solving aspects challenge students to become "active participants in the learning process" (Harper & Hedberg, 1997, p. 11). The program provides a metaphor to the real world that encourages students "to apply scientific concepts and techniques in new and relevant situations . . . throughout the problem-solving process" (p. 12; see also Linser & Naidu, 1999). The simulations embedded in the program enhance the problem-solving process by allowing students to become involved in a realistically situated process where they can manipulate relevant variables and test their hypotheses without risk or consequence and within a reasonable time frame (Harper & Hedberg, 1997; see also Richards, Barowy, & Levin, 1992; Windschitl & Andre, 1998).

This case study focused on biology applications in the *Nardoo* program, specifically dealing with human impact on water quality in the simulated river ecosystem.

Simulations in the Learning Cycle

This case study researchers' interest in simulations in learning cycle lessons stems from their use of learning cycles for constructivist teaching (e.g., Abraham, 1997). The learning cycle format used for this study consists of three phases: exploration, concept/term introduction or invention, and concept application or expansion (Lawson, 1995; Beisenherz & Dantonio, 1996; Sunal & Sunal, 2000) with slightly different terms being used by the different authors. This paper uses the phase terms and descriptions described by Sunal & Sunal: exploration, invention, and expansion. The exploration phase includes open-ended questions and activities that elicit students' prior knowledge and challenge their alternative conceptions. The invention phase includes construction of new knowledge and is identified with formal instruction. The expansion phase includes applying the new knowledge in different contexts.

Educational research on simulations, as with other topics, tends to focus on formal instruction; however, several researchers have reported effective use of simulations in both pre- and postinstructional situations which correspond to the first and third phases of learning cycles (Gokhale, 1996; Windschitl, 1998; Lee, 1999; Hargrave and Kenton, 2000) Though none of the previous researchers refers specifically to learning cycles, Lawson (1995), a prominent promoter of learning cycles, supports the use of simulations in the application phase of learning cycles "to extend and refine the usefulness of terms previously introduced" (p. 310). The use of simulations after or supplemental to formal instruction appears as an acknowledged strategy by researchers (Lee, 1999). Gokhale (1996), for example, claims that simulations used after formal instruction "offers the student an opportunity to apply the learning material" (p. 37). Windschitl (1998) says that the use of simulations after regular instruction serves as a consolidating experience.

Researchers who support the preinstructional use of simulations do so for similar reasons, including the exploration of concepts (de Jong & van Joolingen, 1998) and setting the context for formal instruction (Gokhale, 1996; Lee, 1999; Hargrave and Kenton, 2000). In addition, Lawson (1995) supports the use of simulations in the exploration phase of learning cycles "when the phenomena of interest cannot be directly experienced given the normal classroom constraints" (p. 310). Lawson also acknowledges the use of simulations in learning cycles to provide motivation, provide an organizing structure, serve as a concrete example, or expose misconceptions and other areas of knowledge deficiency.

According to Gokhale (1996) properly designed simulations used prior to formal instruction "build intuition and alert the student to the overall nature of the process" (p. 37). Hargrave and Kenton (2000) claim that students who experience topics through simulations prior to formal instruction become "active creators of knowledge," assuming greater control of the content and their own learning (p. 54). Windschitl (1998) says simulations can be used to introduce especially challenging or unfamiliar concepts before "didactic" instruction, thus setting the cognitive stage by providing organizational structure. Lee's (1999) hybrid simulations, which include both presentation and practice modes, can stand alone as preinstructional resources, although claiming that few studies have been done to examine the effectiveness of such simulations.

The purpose of this case study was to develop, administer, and collect student data on learning cycle lessons that use simulations in all phases of the cycle (but not necessarily in every phase of every lesson). Initially, simulations were used only in the invention phase, allowing students opportunity to become familiar with the resource. In subsequent lessons, simulations were integrated into the expansion phases and exploration phases. One later lesson employed the use of simulations in all three phases.

Method

Participants and environment

In this case study, 14 upper elementary and 17 middle school science students were observed, along with their teacher, using simulations as they engaged in learning cycle lessons revolving around river ecosystems. The ages of participants in this study ranged from 9 to 13 years old and, according to their teacher, they exhibited a range of disabilities. The students, who go a private school with a philosophy based on Gardner's (1993) theory of multiple intelligences, display a seemingly disproportionate number of special needs. The teacher reported the following issues for seven of the participants:

- Student 1 has a genetic disorder and, according to family doctors, would never learn to read or write, but can do both.
- Student 2 has speech and learning disabilities, takes speech lesson once a week, and has weak, small muscle control.
- Student 3 has Asperger's Syndrome, a form of autism, is socially unskilled, and tends to view the world literally.
- Student 4 has a serious form of dyslexia.
- Student 5 has attention deficit hyperactive disorder.
- Student 6 has severe attention deficit disorder.
- Student 7 works with a specialist on slight deficits in short and long term memory and writing skills.

The teacher has taught science and mathematics for more than 20 years, mostly in her home country, Colombia, at an American school. Her recent experiences teaching in this country have involved her first intensive use of computer technology. This study was her first experience using simulations in a science classroom setting and her first attempt at doing action research. Having recently completed her master's degree in science education in a constructivist science education program, the teacher was familiar with the advantages of using learning cycle lessons in the science classroom.

The classroom environment in which this case study took place can be considered above average as to technology use and access. The school suggests that parents provide students with laptops to use in the classes and at home. While it is not required that they have them, many do. During activities requiring the use of computers, those students who have their own computers use them, sharing with their classmates, while other use desktop computers provided by the school. The classrooms all have Internet access, including wireless access in the teacher's classroom, which is used by students with laptops and wireless cards. For this study, sufficient numbers of CDs with the program were available so that students could work in small groups, most often in pairs.

Activities and Data Collection

This case study involved action research by the teacher working with the (university) researcher. Initially, the university researcher administered learning cycle lessons that he developed.

Data collected included videotaped sessions of students using the simulations, teacher journal, student field logs, student concept maps, student and teacher interviews, and products of student activities. The students were assessed for their understanding of concepts during and after completing the learning cycle lessons. The students also completed three surveys that were developed and administered by the teacher. Two surveys focused on student experiences with computers, student beliefs about the usefulness of computers, and how they like using computers. A third survey focused on use of the *Nardoo* program.

The teacher-administered surveys mainly provided attitudinal information on the use of computer technology. As in many such surveys, students reported a wide range of attitudes about their competence and confidence in using the technology, as well as the perceived advantages and disadvantages of using it. Because of the range of competence, those students who are the most computer literate found the exercises easy and finished quickly. Those students on the other end of the competency scale, found the computer-based tasks somewhat intimidating, even when they were able to complete assigned tasks successfully. Some students preferred to use computers for all their school activities while others felt it was more efficient and easier to use pencil, paper, and print resources, as opposed to computer programs and the Internet.

This case study mainly covers results from four learning cycles developed by the university researcher and additional activities developed by the teacher to follow-up on the learning cycle lessons, especially related to transfer of learning from simulations to real-world activities. The first learning cycle lesson developed by the university researcher employs the program simulations in the expansion phase, which allowed the students to develop understanding of the concepts before using the simulations (e.g., de Jong et al., 1999). After the exploration phase, which gets at the students' prior knowledge of biodiversity and ecosystem concepts using a KWL chart (Egan, M. (1999), the students did the first activity on biodiversity from the classroom edition materials (Rapose, Cesaro, Poirier, Collins, Toppi, & Plante, 1997). The students related this activity to their school environment to help them develop working, or operational, definitions of the concepts. They collected data in tables and wrote their working definitions.

For the expansion phase of the first learning cycle, the students did the second biodiversity activity, using the CD simulation of the river ecosystem. For most of the computer-based activities, students worked in small groups of two or three. To reduce the anxiety of using the technology for the first time, the activity was treated as a contest to see who could find the most organisms in the different ecosystem zones. As an expansion phase activity, the use of the simulations allowed the students to relate biodiversity concepts studied during the invention phase to the simulated river ecosystem. The students discussed their findings and their ideas for differences in zones before completing the KWL chart (what was learned) to finish this lesson.

In the second learning cycle, the students worked with simulations in the invention phase, using the simulations to construct knowledge about food chains and webs. In the exploration, they began another KWL chart and then, in small groups, they created food webs (concept maps) by making connections (links) between organisms (picture cutouts). Their arrangements represented their prior knowledge on the relationships among the organisms. Before gluing pictures, the groups discussed their food webs and made adjustments to begin the invention phase. They then went to the CD to study organisms and their relationships in the simulated ecosystem. They created tables to collect data on the organisms they found. After sufficient time interacting with the simulations, they gathered as a class to discuss findings and reach a consensus about the relationships among the organisms and diversity issues.

To begin the expansion phase of the second learning cycle, the students created food webs based on the simulated ecosystem findings (new concept map). Comparisons between initial concept maps from the exploration phase and the new maps showed much greater complexity in numbers and linkages (The students were asked to make predictions of changes in population numbers based on their webs. They then completed the KWL chart (what was learned) and wrote an essay in their field logs about organism interdependency using their food webs as a resource.

The third learning cycle lesson focused on algal blooms without using the CD simulations. The teacher guided the students through this lesson. After exploring students' prior knowledge on the topic, the students used print resources to find out more. They observed algae under microscopes and sketched and labeled what they saw. A class discussion summed up the invention phase. In the expansion phase, the students began an experiment involving growing algae under different conditions (with or without added nutrient). They recorded their observations in data tables over the next few weeks counting algae in drops from the different samples under microscopes. At the end of the observation period, they compared the results and discussed them in relation to sources of nutrients and effects observed in the Nardoo ecosystem up to that point.

In the fourth learning cycle, simulations were used in all three phases (see appendix). This fourth lesson focuses on water quality issues, especially human impact. In the first phase, the small groups of students used the CD to explore the meaning of water quality and the water quality index. They discussed their findings with the whole class. In the invention phase, the discussion continued, focusing on the factors used to develop a water quality index. The students were told that they would apply the knowledge gained in this lesson to measure water quality in the environment nearby. The students created tables to collect data from the CD simulations and they were guided in the use of tools for collecting that data. After sufficient time, they gathered as a whole class to discuss their findings. They wrote about the results in their field logs.

In the expansion phase of the fourth learning cycle, the students used the CD simulations again to complete a research table on sources in the river ecosystem zones that affect water quality. After allowing sufficient time to collect data, the students gathered as a class to present findings and discuss environmental factors affecting water quality. The students compared the different ecosystem zones, representing different levels of human impact, and discussed the implications. To complete the lesson, they added to their comments in their logs. In subsequent activities, the teacher had the students experiment further with algae, using the classroom edition materials and the CD. The students used the simulation tools to collect and graph data on a variety of variables. One of the culminating student products was the creation of educational brochures to inform fictional communities on various water quality problems in those communities, including suggestions for resolving the problems.

Results

Often, just a difference in curricular resources, especially when technology is involved, results in improvements in students' attitudes about learning. Such was the case with the following student:

> "It has been very rewarding to see that the student, who normally has difficulty staying on task during a normal class period, absolutely loved the CD" (excerpt from teacher report on the study).

The teacher goes on to say, "I have obtained better results from the students that never do homework from the projects derived from the material from the CD."

In this case study, student results and teacher self-reporting showed that the use of simulations in learning cycle lessons provided a meaningful learning experience for both the teacher and the students.

> "I was excited about using simulation software in my classroom. I learned along with my students to use the CD. The *Nardoo* CD gives an accurate view of the effects of human activity on the ecosystem of a river. It is done in a very interactive form, in which the students constantly have to search for the answers. They had to go in the river sites and also into the information file cabinet" (teacher report).

As mentioned in the data collection section, the results of pre-instructional and post-instructional concept mapping showed a richer variety of concepts and increased linkages among those concepts (e.g., Robinson, 1999; Gabel, 1999; McClure, Sonak, & Suen, 1999; Hurwitz, Abegg, & Garik, 1999). Overall, the teacher observed the following:

> "I did not have a very clear picture of how much they were going to gain from this study, but in my opinion, surprisingly, in their assessment, they showed

> evidence of good understanding of the concepts. In particular, the one on pollution. . . Using the learning cycle with simulations I think gives the student better chances to gain more concrete knowledge. Their inquiries can be self-answered by searching in the simulation. It is a hands-on activity and, at the same time, they are being active learners."

The teacher also was better able to bridge student understanding between print materials and simulations and real-world experiences:

> "They like the presentation of the material and how realistic it became if you were thinking of an actual river case scenario. . . . In the particular case of the study of the algal bloom, it was great to see the changes in the river when you alter the quantities of the chemicals. This way they could visualize their understanding. They would not be able to see this type of situation in a normal setting, unless it is happening. . . . Now that the students are familiar with terminology and they also have much broader information on the topics covered, it will be much easier to go out in the field and perform actual measurements and experiments."

In one early example of transferring knowledge to real world situations, the teacher reported the following:

> "One of the activities outside of the classroom, at the school park, students measured a square meter area as their site to start studying the biodiversity of the school grounds. They have recalled the vocabulary used in the CD and they seem very familiar with the process to follow. During the activities in the CD, they had to really search for the animal population. During one of the activities at the school's park, one of the students' comment was 'finding a bug here is as hard as in the Nardoo.'"

Conclusion

This case study, thus, provides an example of the effective use of simulations in learning cycle lessons for upper elementary and middle school students engaged in environmental studies. The *Nardoo* program conforms to all aspects of the simulation definition that Hargrave and Kenton (2000) derived from the research literature: "A nonlinear and manipulable model, representing a real or imagined phenomenon, that has the ability to present, either visually or textually, the current state of the model" and that allows the user "to track his/her progress within the model and provides feedback in realistic forms" (p. 48).

Harper and Hedberg (1997) caution that constructivist learning situations may require students to have developed organizational skills or they will not do well in a cognitively complex learning environment (see also Windschitl & Andre, 1998). In their efforts, the developers stuck to the basic constructivist question, "How can we best support knowledge construction?" realizing that the learner will only extract from a program "what sense they make of it, not what the designer intended" (Harper & Hedberg, 1997, p. 6). Even though this program was developed from a strong pedagogical base (Harper & Hedberg, 1996, 1997), how students learn through its use in the given circumstances remains unknown (Jackson, 1997; Snir et al., 1995). Developing constructivist-based learning cycles, as described in this case study, provides one method for facilitating students in using the simulations. An anticipated outcome is to have the learner in control of the learning process, a major characteristic of discovery learning (de Jong et al, 1999).

As mentioned in the section on study participants, many of the students had special needs. One of the students, the one with Asperger's Syndrome, has difficulties staying focused on the classroom tasks. However, the student thrived in working with the CD simulations. Wanting to learn more, the student made arrangements to borrow the CD to use at home during the spring break. The teacher also reported on the advantages of using simulations for being able to study relationships among many variables within a short time frame, as well as the opportunity for students to interact with models—and develop their own models—in very much the same way as engineers and research scientists. She referred specifically to the students' ability to work with the many variables affecting water quality, obtaining results within minutes that would take hours or days to accomplish in real systems.

While many researchers agree that simulations should not or cannot replace students' hands-on experiences (Richards, Barowy, & Levin, 1992; Snir, Smith, & Grosslight, 1995; Coleman, 1997), simulation models can lend much greater efficiency to experimentation. A simulation that runs in minutes instead of the several days or weeks required by physical methods allows students greater efficiency and enables them to investigate many more variables (Snir et al., 1995; Coleman, 1997). Additional advantages of simulations include allowing students to perform virtual experiments that otherwise would be too dangerous or expensive (Windschitl, 1998; Steed as reported in Jonassen, 2000).

The teacher also reported that, in using simulations, a teacher does not have to worry about the students experimenting with potentially harmful chemicals—at least in their initial experiments. One of the advantages of the simulations is that students can gain experience with the tools and chemistry that can be transferred to experiments using real materials. The teacher also remarked on advantages of using simulations when the real equipment, materials, and assistance just is not available for classroom use.

The teacher, reporting on her thoughts during the study, discussed the difficulty veteran teachers have in changing teaching practices, especially when it comes to learning to use technology. She discussed the importance of doing hands-on labs with students, as well as the advantages of combining these with appropriate simulations, as discussed in the research literature. She remarked on the importance of depth in learning that could be achieved through the use of appropriate tools and resources.

According to Linser & Naidu (1999), the use of simulations for problem-solving activities in a context can provide effective situated learning experiences for students (see also Lave & Wenger, 1991; Harper, Hedberg, Wright, & Corderoy, 1995; Looi, 1998). Problem-oriented simulations help develop students' higher order thinking skills and improve cognitive strategies for recall, problem solving, and creativity (Vennman, Elshout, & Busato, as reported in Gokhale, 1996). In addition, Gokhale says "simulations that employ an array of media will help bridge the gap between learning styles of students and teaching styles of instructors" (p. 37). Roberts et al. (1996) recommend three strategies for integrating science simulations into classrooms:

- Teacher education courses must include science simulations as an important science learning tool.
- Science education faculty must be sensitive to the delicate balance between direct teaching and student exploration.
- Science educators, by involving their students in computer simulations, must develop ways to model this dynamic balance in their preservice and inservice courses (p. 55).

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Appendix

An example of a learning cycle using simulations in all phases.

Learning cycle lesson plan four: Human impact on water quality

Exploration

Objectives: Students will be able to develop an operational definition of water quality using the CD resources.

Materials: Exploring the Nardoo CD

Procedure:

- Ask students what they think water quality means.
- Ask them what they think might determine/affect water quality.
- Ask why water quality might be important.
- Have students in pairs go to the Nardoo CD and enter the "Water Research Centre."

- They are to click on the "computer" in the Centre and search for information on "water quality" and "water quality index."
- The students should take notes on what they find. The instructor can assist students in using the notes module to grab relevant information. (Be sure that they are familiar with the "linked media" button.)
- When a student finds a good article, have her or him give the title so that the rest of the class can look at it and take notes. They can save notes to the computer drive for later use.
- Allow sufficient time for the search and then have each pair report to the class on what they have found.
- Ask how the information they found on the CD added to what they thought was involved in determining water quality.
- Get a class consensus on the definitions of water quality and water quality index.
- Ask how they think the factors that determine the water quality index can be measured.
- Ask students where in the community they would like to determine the water quality index (and why).

Evaluation: Instructor will monitor student participation in expressing ideas about water quality before and after using the CD. The instructor will monitor student participation and cooperation in using the CD and taking notes on their findings.

Invention

Objectives:

- Students will be able to use an environmental simulation to investigate water quality issues.
- Students will use a simulation to improve their understanding of water quality and its impact on organisms.
- Students will be able to use a simulation to develop an understanding of the impact on water quality as a result of a particular human activity.

Materials: Exploring the Nardoo CD

Procedure:

- Review the significant information found on the CD. Discuss the way to determine the water quality index based on life found in the water. Ask the students if they think they could do this same measurement in a real water source.
- Discuss the factors that determine water quality involving the water itself (salinity, turbidity, and phosphorus. Tell the students that in the near future they will make measurements to obtain the water quality index of nearby water using these factors but, for now, they will practice determining water quality using the CD and studying organisms in the Nardoo River.
- Instruct the students in creating data tables that includes the following column and row labels:

Table A, Blackridge & Merringurra Regions—Zone 2, column 1 heading, "Organisms"; column 2, "Upstream"; column three, "Adjacent"; and column 4, "Downstream." Under "Organisms," rows should be labeled "Very sensitive," "Sensitive," "Tolerant," Very tolerant," "Water quality index," and "Water quality."

Table B, Blackridge & Merringurra Regions —Zone 1, same column and row labels as in Table A.

- Ask the students what they think is involved in extracting sand and gravel and why that is done. Ask if they have seen such an operation, where, and how did it look.
- In their pairs, have students go to Zone 2 of the Blackridge & Merringurra regions on the CD.
- Have them select the "tools" button and the click on "stream quality."
- They are to determine the stream quality for three areas of the Blackridge region for this time zone. The first area is upstream from the sand and gravel operation, the second area is next to (adjacent) this site, and the third area is downstream from the site.
- Have them record their data in the Table A. Instructor assists students in collecting data.
- Next, have them do the same for Zone 1 of the Blackridge & Merringurra regions (a time before the sand and gravel operation), testing the stream in the same three locations.
- Have them record their data in Table B.
- After allowing sufficient time for data collection, bring the students together again and ask them to compare the types of organisms found before and after the operation extracting sand and gravel.
- Between which areas is the change the greatest?
- Ask the students how significant they think the impact in water quality has been as a result of the sand and gravel extraction operation.
- Have the students describe their findings and ideas about water quality in their science journals.

Evaluation: The instructor will monitor student participation in creating data tables. The instructor will monitor student participation and cooperation in using the CD and recording data in their tables. The instructor will collect completed data tables to evaluate for thoroughness of collected data. The instructor will review journal entries for understanding of water quality issues and thoroughness of content.

Expansion

Objectives: Students will be able to use an environmental simulation to describe several additional ways in which human activity has an impact on water quality.

Materials: Exploring the Nardoo CD

Procedure:

1. Review factors that affect water quality (salinity, turbidity, and phosphorus).
2. Have the students create a research table with the following categories:

Type of Impact: Sewage

Causes: (leave sufficient space for data)

Effect on river: (leave sufficient space for data)

Type of Impact: Nutrients

(same subcategories for this and all of the following types)

Type of Impact: Toxic Substances

Type of Impact: Sediment

Type of Impact: Channel Alteration

Type of Impact: Flow Changes

3. Have students go to the PDA on the Nardoo CD and click on Zone 2 of the Blackridge region.
4. Have them navigate the Nardoo River through all four regions using the cursor icon to look for news stories involving the impact of human activity on the river. They should focus their research on the categories in the research table they created.
5. The students can use the notes module to grab relevant information and review it for adding to the research table.
6. Have the students repeat this procedure for Zones 3 and 4.
7. After allowing sufficient time for the students to collect data, bring the class together to discuss their findings.
8. Ask the students what kinds of human activity have caused sewage to be deposited in the Nardoo River.
9. Ask the students what kinds of human activity have raised nutrient levels in the river. Ask them what adverse effects these nutrients have had on the river. Remind them of their study of algae and nutrients.
10. Ask the students what kinds of toxic substances have been found in the river and what these have done to it.
11. Ask them what kind of human activity has deposited sediment to the riverbed of the river. Ask if this activity has any negative impact on the river and have them explain why.
12. Ask the students if the Nardoo has undergone any kind of channel alteration and, if so, how has that impacted the river.
13. Ask them if the Nardoo flow has been affected by human activity and have them explain how.

14. In each of the above cases involving types of impact, have the students compare the three zones and explain the differences among them.
15. Have the students add to their ideas about human impact on water quality in their science journals.

Evaluation: The instructor will monitor student participation in creating the research table. The instructor will monitor student participation and cooperation in collecting data using the CD. The instructor will collect and evaluate student data tables. Review science journals for understanding and thoroughness of discussion.