Comparing the Effectiveness of System Dynamics with Traditional Methods of Learning about Wetland Ecosystems

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Abstract

This paper describes the purpose and design of a study that will compare the effectiveness of a system dynamics-based lesson with a traditional, lecture-based method of learning about wetland ecosystems. The study will test the hypothesis that students taught using a system dynamics approach will meet objectives, that are a combination of science objectives from the Nevada Department of Education and United States Department of Education, with a higher achievement level than those taught using a traditional teacher-based approach. The more holistic approach of system dynamics lends itself particularly well to environmental education because it focuses on the whole system and feedback within the system. Fourth grade students from the Las Vegas school district will participate in one of two treatments, as the experimental or the control group. Students in the experimental group will be presented with a lesson based on system dynamics models about the Wetlands Park Nature Preserve (WPNP) ecosystem in Las Vegas, Nevada, while students in the control group will receive a traditional lecture based on the same material. Students will be given a pretest, prior to instruction, and a posttest two weeks after instruction to assess students' ability to meet the learning objectives described below.

Introduction

In a survey study, Simpson and Oliver (1985) found that in order to get more adults engaged with and concerned about environmental issues, they must develop an understanding of the value of environmental resources and processes in childhood. Studies have also found that traditional methods of teaching about the environment are limited in their ability to engage students. By traditional methods of learning, we mean lecture based learning. Teachers, O'Hara and O'Hara (1998) found that although the world outside of the classroom has changed, today's method of teaching remains similar to the 19th century, where students take notes as the teacher lectures to them for the majority of the time that they are in the classroom. Teachers spend approximately 80% of their time lecturing to students (Steinberg, 1997). In the traditional classroom, students recount facts on tests and individual work is stressed, while teachers direct activity in the classroom and initiate the learning of new concepts (O'Hara & O'Hara, 1998). By interviewing students, Steinberg (1997) found that students spend the majority of their time on the individual activities of taking tests, doing seatwork, taking notes, and listening to lectures. After years of teaching in the classroom, O'Hara and O'Hara found that today's students excessively failed final exams, memorized, regurgitated, and forgot important concepts, had poor study, wanted step-by-step instructions for solving problems, and thought linearly (1998). Students are unprepared to enter the working environment through traditional learning methods. Outside of the classroom, students become workers who are expected to work in groups, do not receive continuous direction from a supervisor, are expected to be self-directed and solve problems, and they are expected to gather, analyze, and disseminate information individually (Gordon, 1997 & Thompson, Mehta, & Schaffnit, 1998). Students are not able to make the transition from constantly taking specific directives from a supervisor, the teacher, to making decisions and being self-directed. In his 1998 State of American Education Address, Richard Riley, the United States Secretary of Education from 1993-2001, stated that "we can not sit still rooted to the chalk board and pencil at a time when a 12-year old can literally touch his or her mouse pad and travel from web site to web site around the world" (Riley, 1998). Traditional education no longer meets the needs of students nor workers, so it must be transformed to meet today's needs.

We propose a more systems-based introduction to environmental education, with a curriculum stressed critical thinking skills, decision-making skills, and learner-directed learning. This type of curriculum will give students a better understanding of both the dynamic processes in the environment, greater appreciation for the value of protecting ecosystems functions, and the ability to easily transition students from the school environment to the real world. These results are particularly critical in Las Vegas, NV, where the Clark County Wetlands Park Nature Preserve (WPNP) functions to protect the water supply of the area. The WPNP is a constructed wetland system that was built to protect Nevada's supply of water and to function as a habitat for wildlife. The wetland system treats non-point source runoff from the entire Las Vegas Valley upstream from the municipal water supply intake in Lake Mead. In order to protect this valuable habitat, people must understand the dynamics of the wetland system.

Background

In a survey of sixth through tenth grade students, Simpson and Oliver (1985) found that as students progress through school from elementary school to high school their interest in science drops, their attitude towards science changes from positive to negative, and their achievement in science declines. Students in elementary school receive very little instruction in science due to the focus on reading, so they enter science courses in middle school with an inadequate background and mixed feelings about science (Simpson and Oliver, 1985). The period in school from elementary school to middle school is a critical period, because it is the time when the majority of individuals develop their most lasting impressions about science (Simpson and Oliver, 1985). Students that do not have a good experience with science tend to stay away from it and become part of the science illiterate (Simpson and Oliver, 1985). In their survey with students in North Carolina, Simpson and Oliver (1985) found that science curriculum creates students with a negative attitude about science and ones that do not want to take more science courses during high school or college. In a follow-up study to their 1985 study, Simpson and Oliver (1990) found that as students progress through school, their attitude towards science, based on an attitude towards science scale which includes likeability, enjoyment, and feelings towards science, declines each year. Their research shows a steady decline in attitude from sixth to tenth grade, with attitude reaching near neutral by tenth grade. Motivation for achievement in science also shows a steady decline that is similar to the decline in attitude. By tenth grade, motivation to achieve reached near neutral (Simpson and Oliver, 1990).

Simpson and Oliver (1990) found that the way students feel toward science and their ability to succeed in science by tenth grade is a good predictor of science achievement through the remainder of high school. The attitude that a student has towards science influences the amount of exposure the student has in science. One of the strongest influences towards their attitude about science is experience in the classroom. Students formulate their attitudes towards science and further involvement in science through their experience in science classrooms (Simpson and Oliver, 1990). By increasing positive experiences in the classroom, students develop a better attitude toward science and greater motivation to achieve in science.

Students are not interested in science because with the current curriculum, students are given facts without a frame of reference to connect those facts with the complexities of life. It is up to the student to integrate facts together in order to understand how the world operates (Brown, 1992). Traditional education emphasizes reductionism, despite research that indicates a more holistic approach to learning is preferable. Reductionism emphasizes students learning by building concepts and skills from parts to wholes. This type of learning is not effective because students stop learning before all of the parts are presented and before they can see the whole (Costello, 2001). Learning facts that are not attached to meaning is useless for students (Brown, 1992). We propose, that by anchoring facts in meaning, using simulation models, students will learn more effectively.

Standards for science achievement in school are set by each state individually. In Nevada, between 3rd and 5th grade, students are expected to understand (1) that science involves asking and answering questions and comparing the answers to what scientists know about the world, (2) how to draw conclusions from scientific evidence, (3) that graphical representations of recorded data can be used to make predictions, (4) models are tools for learning about the things they are meant to resemble, (5) observable patterns can be used to organize items and ideas, (6) the benefits of working with a team and sharing findings, and (7) the processes of the water cycle (NDOE, 2006). In order to meet these standards, students must use critical thinking skills, evaluation skills, and must understand different ways of organizing information.

We propose that a more systems-based introduction to environmental education will enable students to meet the standards set by the Nevada Department of Education (NDOE) better than the traditional approach, give students a better understanding of the dynamic processes in the environment, and a better appreciation for the value of protecting ecosystem functions. By meeting the standards of NDOE better, we mean students will score higher on an assessment exam that tests knowledge, comprehension, and application questions where students must apply critical thinking and evaluation skills to different questions than students taught using the traditional lecture-based approach. We hypothesize that students will also score higher on the assessment test on questions about the dynamic processes in the ecosystem and will score higher on an environmental appreciation evaluation after learning with a systems based approach than the traditional approach.

The environmental appreciation aspect of this assessment is particularly critical in Las Vegas, NV, where the WPNP functions to protect the water supply of the area. The WPNP is a constructed wetland system that was built to protect Nevada's supply of water and to function as a habitat for wildlife. The wetland system treats non-point source runoff from the entire Las Vegas Valley upstream from the municipal water supply intake in Lake Mead. In order to protect this valuable habitat, people must understand the dynamics of the wetland system.

The purpose of this study is to compare the effectiveness of learning about a wetland system using a traditional, teacher-based instruction method versus learner-directed lessons using system dynamics. One group of students is taught about wetland dynamics using the teacher-based approach of a lecture. The other group is taught using role-playing simulations and system dynamic models on the computer (Figures 1 & 2). By using models of an area that is important to the local environment, students will become more engaged, because changes in the area influence their lives. This study is important in meeting the standards set by the NDOE, increasing the effectiveness of learning, and enabling schools to encourage student awareness of environmental management issues.

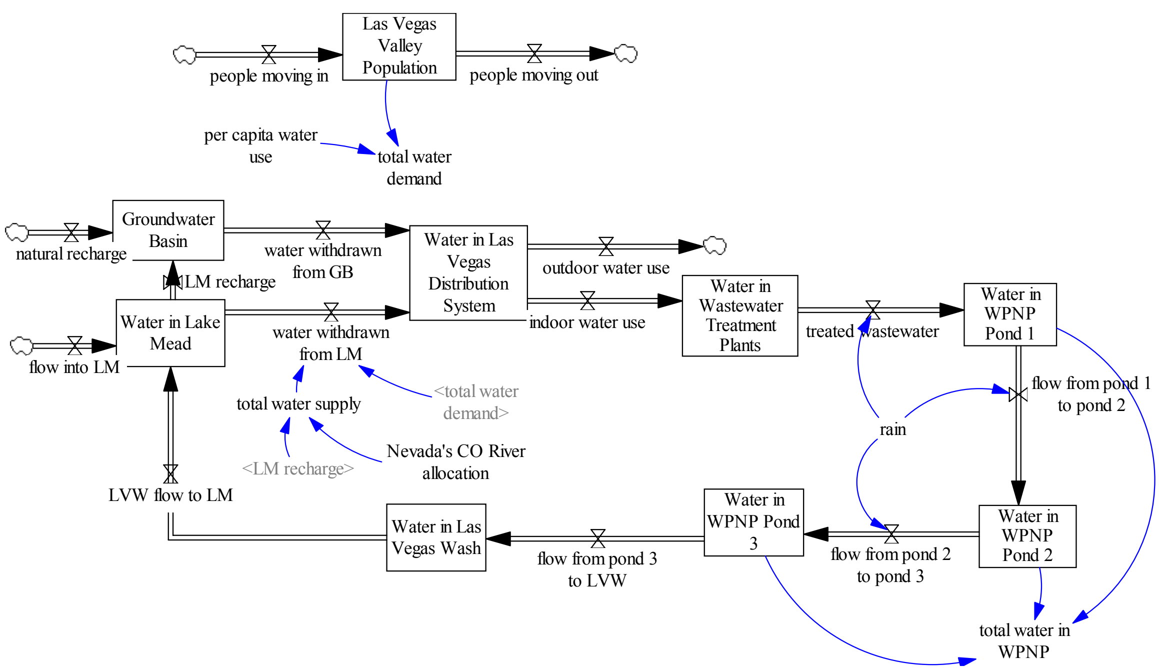

Figure 1: Las Vegas Water System

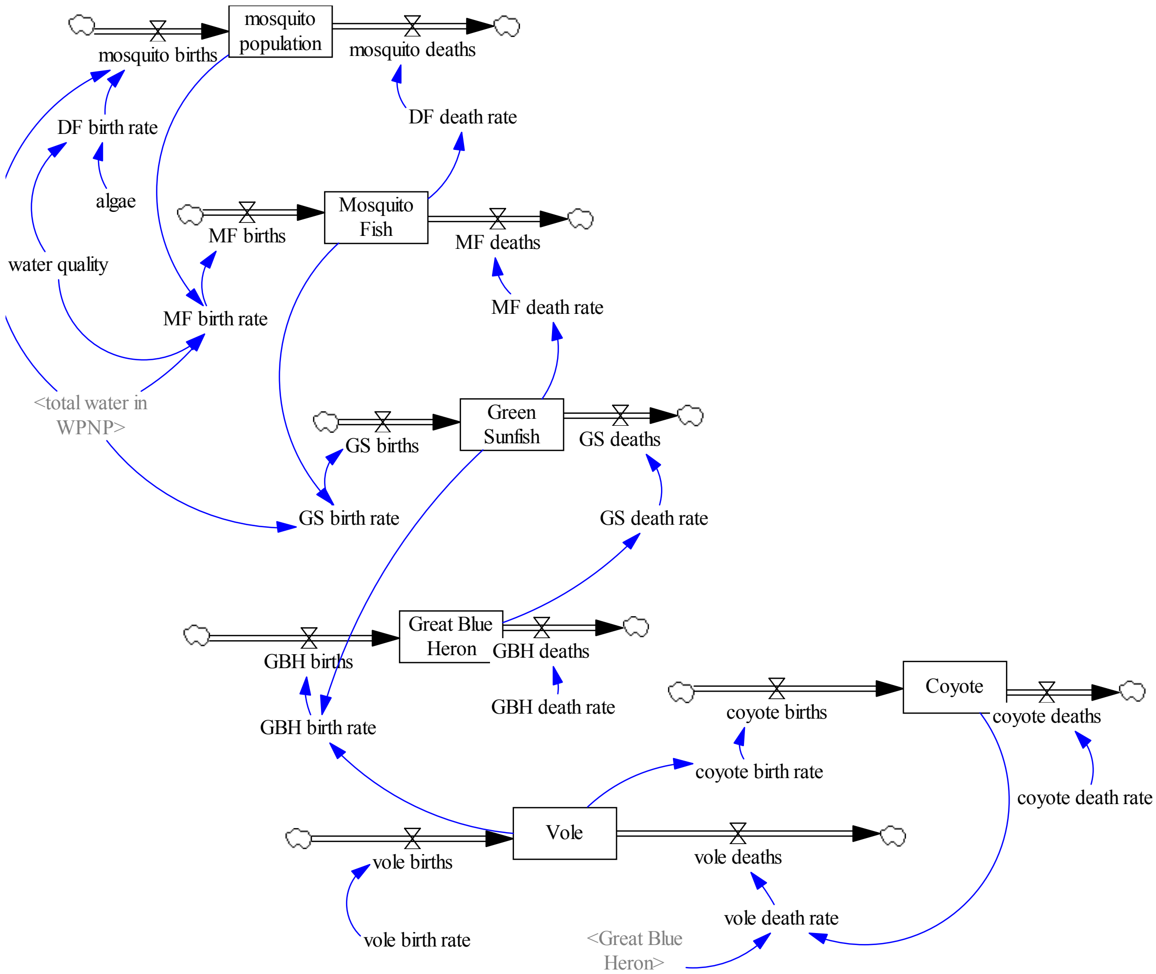

Figure 2: Food Web in the WPNP

Theories of Learning

Learning is defined as either a relatively permanent change in behavior or a relatively permanent change in mental representations or associations as a result of experience (Ormrod, 2004). One way to evaluate whether learning has occurred is to evaluate changes in a person's behavior. For example, the learner might: perform a completely new behavior, change the complexity of an existing behavior, or respond differently to a particular stimulus (Ormrod, 2004). Several theories of learning deal directly with learning in the classroom (e.g., constructivism, behaviorism, Piaget's developmental theory, brain-based learning, and multiple intelligences) (Ormrod, 2004). Terenzini (1999) found that the degree to which learning occurs is correlated with the degree to which the learner is directly involved in the learning experience. Learning requires the active participation of the learner, so students have to play a role and be involved in their own learning process in order for learning to be acquired. For long-term memory, and to ensure that adults stay interested in environmental issues, material has to be retained and the learner must be able to apply the learning to a different, but related, problem, or a problem in a different setting. Learning is most effective when it is set in a real context or has real meaning. When students are interested in a problem and are able to draw on previous knowledge, they become more interested and better able to retain the material (Terenzini, 1999).

One of the problems with trying to get students to learn about a subject is that they hold onto their mental models, even if those mental models are based on incorrect information. Mental models are models that remain in our heads and are a way of categorizing experiences. In contrast, conceptual models are tools that are used for teaching and understanding physical and natural systems. Ideally, there should be a direct and simple relationship between the two; however, when the two are in conflict is when learning opportunities arrive. Because the teacher holds the correct conceptual model, her task is to elicit the mental models of his students and decrease the conflict via teaching. Teaching is the task of bringing forth student mental models and providing sufficient experience and evidence to allow students to adapt, modify, reject, or enhance their own mental models (Costello, 2001). Glynn and Duit (1995) found that teachers must be aware of the significant differences that often exist between their conceptual models and the mental models of their students for instruction to be successful. This is important because student's mental models may contain misconceptions and tend to be resistant to change.

Costello (2001) showed that mental models are built on assumptions that evolve over time as a result of experience and prior learning. In order for children to change their mental models, they must be able to understand their own mental models. Techniques for eliciting mental models include mind-mapping tools, flowcharts, annotated concept maps, Venn diagrams, causal loop diagrams, stock/flow maps, and other visual organizers. These techniques not only identify components and variables in a system, but they also make behavioral connections between the variables. Using methods such as stock/flow maps within a simulation allows students to play with their assumptions, test various beliefs, and see the response of the system to their inputs. By using visual tools with class discussion, learning is enhanced. Costello (2001) states that thinking and discussion leads to more thinking. By thinking aloud, discussing, and communicating their own though processes to other, students enhance their thinking and problem solving skills. These types of mapping tools are also important for students to integrate knowledge. Students have a tendency to compartmentalize knowledge if it is presented in isolation, so these types of mapping activities enable students to integrate their knowledge (Kali, Orion, & Eylon, 2003).

To determine whether learning has occurred after an intervention many studies use Bloom's Taxonomy of Educational (e.g., Çepni, 2006; Chang, 2001; Klein, 1972; Roberts, 1976; Roberts, 1978). Bloom developed a hierarchy of educational objectives, known as Bloom's Taxonomy, in order to divide cognitive objectives into subdivisions ranked from the simplest to the most complex. Bloom's Taxonomy consists of six components shown in Figure 1: knowledge, comprehension, application, analysis, synthesis, and evaluation. Each component builds on the preceding component, so that it is assumed that one learns the lower levels before one can use the skills above it. Knowledge consists of memorizing verbatim and being able to remember information but not understand it. Comprehension involves restating an idea in one's own words, paraphrasing, summarizing, translating, and understanding information. Application involves using information to solve problems, transfer abstract or theoretical ideas to practical situations, and identifying connections and relationships and how they apply.

Analysis requires identifying components and determining arrangement, logic, and semantics. Synthesis entails combining information to form a unique product that requires creativity and originality. Evaluation involves making decisions and supporting reviews, so it requires understanding and values students (Carneson, Delpierre, & Masters, 1996). Through action research, where participants systemically examine their own educational practice, the Waters Foundation (2006) found that within the writing and reading skills, students can retell and summarize and identify cause and effect relationships, comprehension level of Bloom's Taxonomy, identify relationships between components, application level, and analyze information, analysis level. For this study, we believe that when testing students on wetlands, they will reach the evaluation level of the taxonomy.

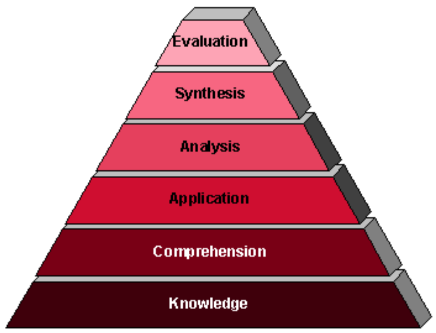

Figure 3: Bloom's Taxonomy of Educational Objectives (Image from: University of South Florida, 2005)

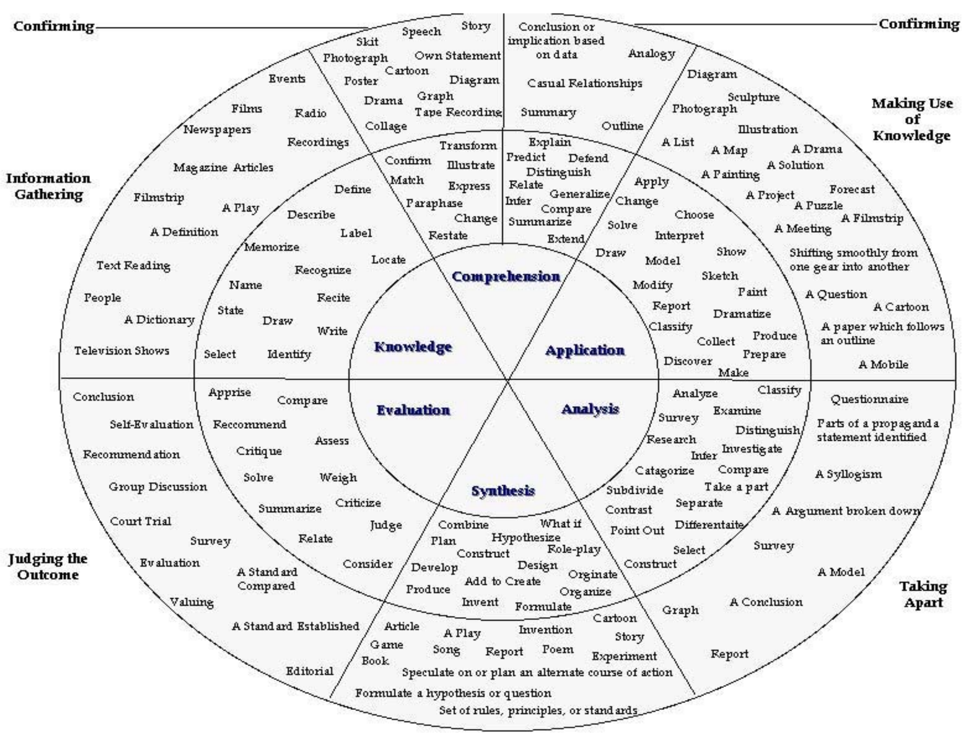

Figure 4: Bloom's Taxonomy for Multiple Choice Questions (Image from: University of South Florida, 2005)

Anderson (2005) revised Bloom's Taxonomy into the Taxonomy Table (Figure 5) with a group of educators and researchers. The revisions are based on the structure of educational objectives, advances in cognitive psychology, and on different attempts to classify educational objectives after the publication of Bloom's Taxonomy of Educational Objectives. The Taxonomy Table changed the horizontal dimension of Bloom's Taxonomy, the Cognitive Process Dimension, by changing the noun forms of the original categories to verb forms: remember, understand, apply, analyze, evaluate, and create. Anderson (2005) also added a vertical dimension, the Knowledge Dimension, to the table with four types of knowledge: factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge. Bloom's Taxonomy was arranged from simple to complex and from concrete to abstract. The hierarchy was believed to be cumulative, so that mastery of each lower level was a prerequisite for achieving mastery of the next higher level. With the Taxonomy Table, the dimensions are still believed to be hierarchical with lower categories being simpler and more concrete than higher levels; however, idea that it is a cumulative hierarchy was removed. Thus analysis is not a required prerequisite for application (Anderson, 2005). Remember corresponds to the ability to retain knowledge, while the other five categories corresponds to tests of transfer. Retention measures the amount of the presented material someone remembers. Transfer measures how well someone can use what was presented in new tasks (Mayer, 2002).

The Knowledge Dimension of the Table consists of four general types of knowledge: factual, conceptual, procedural, and metacognitive. Factual and conceptual knowledge constitute knowledge of what, while factual and conceptual consists of how to knowledge (Mayer, 2002). Factual knowledge consists of terminology, details, and elements that students must understand for a specific subject (Anderson, 2005). These are the basic elements a student must understand to be familiar with a discipline or solve a problem (Mayer, 2002). Conceptual knowledge is knowledge of classification and categories, principles and generalization, and theories, models, and structures. This type of knowledge requires the understanding of the interrelationships between the basic elements within an entire system that enables the parts of the structure to function together. Procedural knowledge is knowing how to make or do something. This includes methods, techniques, algorithms, and skills, as well as the criteria of determining when it is appropriate to use procedural knowledge. Lastly, metacognitive knowledge is knowledge of general cognition, and awareness and knowledge of one's own cognition. This category includes strategic knowledge, task knowledge, and self-knowledge (Anderson, 2005). The Taxonomy Table allows for the ability to align assessment with the objectives of the class (Mayer, 2002).

	The Cognitive Process Dimension					
The Knowledge Dimension	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
a. Factual Knowledge						
b. Conceptual Knowledge						
c. Procedural Knowledge						
d. Metacognitive Knowledge						

Table 5: Taxonomy Table

Systems Thinking

Systems thinking is a field that views knowledge systemically, and provides a set of tools and methodology for understanding simple and complex systems. A system is described as a whole that consists of parts. Each part in the system affects the behavior of the whole system, depending on the part's interaction with other parts of the system. Behaviors of the system result from the whole and not from the parts. Systems thinkers see both the forest and the trees. They are able to look through the complexity of a system to see and understand the underlying system structure generating changes in the system (Richmond, 1991; Senge, 1994).

By using action research, the Waters Foundation (2006) found that students using systems thinking tolls are able to clarify and visually represent their understanding of complex systems. Students are able to explore their thoughts, perceptions, and mental models through behavior-over-time graphs (BOTGs), connection circles, and causal loop diagrams. BOTGs enable students to depict their understanding of patterns and trends, because they allow students to describe orally and in writing what and how they are thinking. Connection circles and causal loop diagrams allow students to describe their understanding of connections and interdependencies of complex systems. The Waters Foundation found that these tools allow students to make their thinking visible, which allows teachers to identify students' misconceptions (Waters Foundation, 2006). In a pretest-posttest study on the rock cycle, Kali, Orion, and Eylon (2003) found that systems thinking activities provided students with useful cognitive frameworks, which they subsequently used for developing higher levels of systems thinking for knowledge integration activities. Working with computer software, students in the Kali, Orion, and Eylon study (2003) reached the higher levels of systems thinking skills, including synthesis, which students in traditional classrooms do not reach.

Draper (1993) proposes that systems thinking involves seven skills with associated levels of activity that are utilized at difference grade levels. These skills are developed with time starting with (1) structural thinking, (2) dynamic thinking, (3) generic thinking, (4) operational thinking, (5) scientific thinking, (6) closed-loop thinking, and (7) continuum thinking. The first skill is structural thinking, which involves identifying interrelations, what effects what, where things flow, and which things accumulate. This skill can be incorporated into the school curriculum starting in fourth grade. In order to develop the skills of structural thinking, students need to make connections between various content areas, draw simple causal loops, and use simple computer simulations. The other six skills require a foundation in structural thinking and should be developed after an introduction to systems thinking and after the fourth grade (Draper, 1993).

During elementary school, the standards for systems thinking encourages students and teachers to explore systems that they know in terms of family, nature, and the elementary program. Systems thinking should be used to model and understand interrelationships in the curriculum, including literature, social studies, science, language, mathematics, the arts, and school citizenship (Langheim and Lucas, 1993). Langheim and Lucas (1993) suggest that by third grade, students should be able to create maps and models within curriculum content using simple connectors and converters in structured diagrams and causal loop diagrams. Students should also be able to explore maps and models provided by the teacher, modify and extend the maps, and explain why systems are dynamic. Stuntz, Lyneis, and Richardson (2001) believe that by fourth grade, students should be able to build one-stock linear models in teams, make predictions before running a model, generate behavior over time graphs, distinguish between linear and exponential growth patterns, and recognize oscillating patterns (Stuntz, Lyneis, & Richardson, 2001). By implementing systems thinking in fourth grade, students can continue using these tools throughout their schooling. By the end of school, students should use systematic tools to solve problems in their lives and the outside world.

Teaching About the Clark County Wetlands Park Nature Preserve

The WPNP is an extremely important part of the ecosystem in Las Vegas. Most residents; however, do not know about it and do not understand the importance of it in this arid environment. The WPNP is a constructed wetland that receives water from three wastewater treatment plants in Las Vegas. The water from the park flows into the Las Vegas Wash, which flows into Lake Mead, and eventually into the Colorado River. Since all of Las Vegas' water comes from Lake Mead, it is important to insure that the water flowing into the Lake is as clean as possible. The wetland acts as a natural filter for the water flowing into Lake Mead by taking out the contaminants in the water. The WPNP also provides a natural habitat for fish, birds, mammals, and other species that one would not expect to find in a desert environment (Stave, 2003). In a rapidly growing and developing city, like Las Vegas, natural areas are few and always in danger of being lost. In order to maintain the WPNP it is important that people know about it and understand its benefits to wildlife and the community. Middlestadt et al. (2001) found that environmental education interventions can be helpful in meeting the goals of education. By performing this study, students will begin to learn and appreciate this interesting area.

In a study, Chang (2001) found that computer assisted instruction tends to focus on chemistry, life science, and physics, with only limited research on earth science content. Although earth science is an important science in order to make human's aware of the world's deteriorating land, water, and climate, the significance of these topics have not been reflected in the area of science education research (2001). This experiment is based on a lesson about wetlands science. Teaching a lesson about environmental issues using system dynamics models is especially useful for integrating these issues into the curriculum, because they have similar components. Sterman (2000) states that system dynamics can be applied to "any dynamic system, with any time and spatial scale." The biological processes and functions of a wetland system include complex, interdependent feedback within the system. For this experiment, I will utilize three different parts of a wetland system, water, plants, and animals, in order to determine the effectiveness of using simulations in the classroom.

Need for Environmental/Wetlands Education

Environmental education focuses on the biological processes in nature and threats to the environment. The ultimate goal of environmental education is to create an environmentally literate citizenry and to acquire life-sustaining, responsible environmental action skills (Moseley, 2000). The United Nations Educational, Scientific, and Cultural Organization (UNESCO, 1997) defines environmental literacy as "a basic functional education for all people, which provides them with the elementary knowledge, skills, and motives to cope with environmental needs and contribute to sustainable development." The National Environmental Education Advisory Council (NEEAC, 2005) state that the "challenge of environmental education is to raise the level of environmental literacy of the American citizenry as a whole and to ensure the environmental literacy of each successive generation." NEEAC believe that by raising the level of environmental literacy, individuals will be "more capable of analyzing environmental issues and making informed decisions as consumers, employees, parents, youth, students, and voters" (NEEAC, 2005). Although for nearly four decades, polls have shown that the majority of Americans care about a healthy environment, the majority of the population lacks a basic understanding of environmental issues. Through yearly surveys on environmental awareness, it has been shown that Americans can answer fewer than 25 percent of basic environmental literacy questions (NEEAC, 2005).

During the 1970s, the environmental movement created interest in integrating environmental education into the K-12 curriculum. However, this initial attention has not progressed to the integration of environmental education into the school curriculum. Ham and Sewing (1987/88) conducted interviews with elementary teachers and found four barriers that inhibit teachers from incorporating environmental education into their curriculum: (1) conceptual barriers, (2) logistical barriers, (3) educational barriers, and (4) attitudinal barriers. This paper will focus on conceptual barriers and attitudinal barriers. Conceptual barriers occur due to a lack of knowledge about the scope and content of environmental education. The majority of teachers see environmental education as only relevant to science curricula or as a subject separate from their existing curriculum. Teachers need to understand that environmental education should be a part of all subjects, not simply science. By incorporating environmental education into all subjects, students will understand complexity and interconnections that occur in the environment. Attitudinal barriers stem from teachers' attitudes towards environmental education and science. Ham and Sewing (1987/88) found that although teachers tend to have a positive attitude towards the importance of environmental education, they did not conduct environmental education activities often. When lessons are taught, they emphasize learning about the contents of the environment, not on the value and importance of the environment, skill development, or participation in solving environmental problems (Ham and Sewing, 1987/88; Volk, Hungerford, and Tomera, 1984).

Gigliotti (1990) suggests that environmental education initiatives has produced "ecologically concerned citizens who, armed with ecological myths, are willing to fight against environmental misdeeds of others but lack the knowledge and conviction of their own role in the environmental problem." Most people are not willing to make personal sacrifices for the sake of the environment. Individuals selectively screened lessons from their environmental education to construct their own belief structure that does not require them to change their lifestyle. In order for environmental education to be effective, people must see themselves as part of the environment, instead of separate from it. People must understand their individual role in resource depletion and increased pollution and actions that they can take to alleviate these problems. The key variables that influence one's intention to take actions include action skills, knowledge of action strategies, and knowledge of environmental issues. Environmental education needs to make the connection between individual actions and solutions to environmental problems, because specific knowledge about how one can address an environmental problem is a crucial step in changing environmental behavior (Gigliotti, 1990; Middlestadt *et al.*, 2001; Moseley, 2000). Hewitt (1997) tested elementary students using simulations that include wetlands, pollution, energy, world population, endangered species, and individual effects on the environment, which were designed to teach facts, influence decisions, and describe the value of an area. Students were tested using a pretest and posttest format to measure environmentally responsible behavior. In this study, Hewitt found that students who use simulations to learn about environmental topics and had scored low on environmentally responsible behavior increased their scores significantly (Hewitt, 1997)6.

Tanner (1980) used a survey in order to understand the kinds of learning experiences students need from environmental education to become informed and involved in environmental problems. Tanner found that experience of the outdoors in youth, particularly with habitats that were accessible on a frequent basis, has a great influence over adults' environmental activities. By focusing lessons on areas that are accessible to students, will influence their future endeavors (Tanner, 1980). Teaching Clark County students about their local wetlands park will encourage them to visit the park and become involved in its conservation. Tanner also found that teachers who were excited about studying environmental education or showed students' interest in the environment were remembered by their students. In fact, teachers influenced student's interest at all points in their education, from primary school to postgraduate study, and from initial interest in the environment to career choice (Tanner, 1980). Since teachers have such a profound influence over students' interest and activity in the environment, in order to increase the number of adult activists, environmental curriculum must be increased in schools.

A System Dynamics Based Approach

The educational system in the United States is organized so that subjects are separated into distinct units that are not connected to each other. The world outside of the education system is complex and interconnected, so education has less relevance to life. The education system also does not show the dynamic behavior of the world and how it changes through time. As humans, we can grasp static relationships that are not very complex; however, we cannot grasp complex, dynamic relationships. Tools need to be utilized in order to address what is similar between disciplines (Forrester, 1992, 1998; Joy & Zaraza, 1997; Richmond, 1991; Sudnick, 1992). From childhood we are taught that cause and effect are linked in space and time. Thus, we tend to look to local causes that are closely linked in space and time for our observations (Grant, 1998). Currently education follows the following sequence: (1) learn facts, (2) comprehend meaning, (3) apply facts to generalizations, (4) analyze material in its constituent parts, and (5) synthesize material to assemble the parts into a whole. The majority of students never reach the final step of synthesis, so they instead learn information in small components without putting it together in any form (Forrester, 1992, 1998). If information is not synthesized it will not be remembered (Bruner, 1963). Learning should be based on connections of how things influence each other and how past behavior and future outcomes arise from these connections. System dynamics can provide this structure in education. By making connections, insights are transferred and different disciplines become integrated and it provides a common language for mathematics, biology, ecology, physics, history, and literature (Forrester, 1992; Martin, 1997; Meadow, 1991). System dynamics is an approach to observing and analyzing complex systems in a comprehensive manner. System dynamics seeks to understand structure, interconnections between all components, and how changes in one area will affect the entire system and its constituent parts over time (Hight, 1995).

Cognitive scientists suggest that learners could develop a deeper understanding of subjects if they build and manipulate models of the subject or work with a simulation (Milrad, 2002). Simulations include computer-based, dynamic models as well as role-playing. Computers are not essential to create simulations; in fact, it is estimated that approximately half of the middle school and high school system dynamics projects are not computer based (Hight, 1995). It is also not essential that every student have a computer. Lessons can be taught using one computer and a projector, because the entire class creates the model through interactions (Joy & Zaraza, 1997). Using models, students move from understanding a subject at the knowledge level by memorization to understanding the meaning of the subject (Çepni *et al*., 2004). A classroom simulation is a method of teaching and learning that is based on a real life situation. The simulation is designed to replicate the situation as closely as desired and has students assume roles to analyze data, make decision, and solve the problems that occur in the situation. As the simulation proceeds, students respond to the changes within the system by studying the consequences of their decisions that cause subsequent actions and predicting future problems and solutions. During the simulation, students perform tasks that enable them to learn through their decisions and have their learning evaluated. Well-designed simulations simplify real world systems while increasing awareness of the complexity of that system (Costello, 2001).

Çepni *et al*. (2004) and Chang (2001), found in separate studies using computer assisted instruction that this type of instruction is influential on student's academic achievement. Çepni *et al*. (2004) found that although both students using and not using computers performed well in regards to knowledge based assessment, students using computers performed better on comprehension and application levels of the cognitive domain. Chang (2001) found that students with computer assisted instruction performed better on knowledge and comprehension skills, but not on application test items when comparing pre and post-tests. Roberts (1978) developed a social studies computer unit for fifth and sixth grade students and concluded that these students performed better on knowledge, comprehension, and application questions. In a 1976 study, Roberts found statistically significant learning occurred at all levels of Bloom's Taxonomy for fifth and sixth graders studying a word problems unit in order to learn systems thinking. Reviewing the literature, Harris (2002) concluded that instruction using computers in the classroom produced an active learning environment, improved students' performance, cultivated positive attitudes toward learning difficult concepts, increase communication, and could be adapted to all learning styles and levels of instruction. Harris (2002) found that using computers in the classroom maximized advantages and minimized disadvantages of the traditional methods of teaching and learning.

System dynamics models enable users to experiment with complex systems and develop a better understanding of the mechanisms that govern the dynamic interactions. Using these models, learners are able to formulate and test hypotheses about complex systems. Studies suggest that simulation models provide learning advantages (Milrad, 2002). Spector (2000) states that simulations can improve learning and decision making in complex systems because they (1) provide opportunities to formulate and test hypotheses, (2) make clear the causes for unexpected results in a complex system, and (3) promote interaction with other learners struggling to understand the same trends. Draper (1991) found that classrooms that use systems techniques cover the same material as in traditional classrooms, but they learned by researching, thinking, hypothesizing, making decisions, and designing real world components instead of simply memorizing the information. They learn content as a whole system or relationships and dynamics and instead of as parts (1991).

Studies show that students are not engaged in science in their classrooms. There are very few classrooms where the majority of students are motivated to learn about science for the majority of the time. These studies show that students are not in class to learn about science (Costello, 2001). Costello (2001) found that using simulations in the classroom motivates students by keeping them actively engaged in the learning process through requiring that problem-solving and decision-making skills be used to make the simulation run. System dynamics gives teachers tools that they can use to supplement and improve their curriculum about the environment by getting students involved in the learning process. These tools include: behavior over time graphs, stock and flow diagrams, causal loop diagrams, simulation games, and computer models (Lyneis and Fox-Melanson, 2001, Lyneis, 2000). These tools allow education to "shift from one-way to circular causality and from independent factors to interdependent relations" (Richmond, 1993). Using system dynamics, the curriculum shifts from viewing the world as a fixed, stimulus-response relation to viewing it as a complex, interdependent, dynamic process (Richmond, 1993). This change in curriculum will give students the tools to take what they learn in one classroom and apply it to understand the curriculum in other classes better, as well as translate that learning to their lives.

Implementing system dynamics in the classroom has been shown to help students in the development of critical thinking and problem-solving skills. It also helps in their understanding of the curriculum being taught by helping them to ask better questions and recognize connections across subjects. By using system dynamics in the classroom, classes become more learner-centered. The role of the teacher changes from one of dispensing information to a guide helping students construct their own knowledge. Students change from being "passive receptacles" of information to engage in working together to find solutions (Grant, 1997; Lannon-Kim, 1991; Lyneis and Fox-Melanson, 2001; Lyneis, 2000; Stuntz, Lyneis, & Richardson, 2001). Students work in small groups to help one another so that the teacher also becomes a participant in the learning. By working together, students are able to teach themselves and others in a method described as learner-directed learning (Forrester, 1992). With traditional methods of learning where the teaching lectures and the student listens, performance is measured by how much the student can recall of what the teacher lectured about. With learner-directed learning, the student must understand and reconstruct knowledge, instead of simply repeating it (Richmond, 1993; Stuntz, Lyneis, & Richardson, 2001). Students explore by doing, often begin by failing, and then move to success. As students move toward success, we assume that the student has acquired new knowledge and adjusted their mental model (Costello, 2001, Costello *et al.*, 2001).

Teachers implementing system dynamics in the classroom have found that students who study system dynamics are equipped with the skills, perspective, courage, and responsibility to deal effectively with the dynamically complex social, economic, and environmental problems. It gives students the tools and common language to identify and discuss their mental models of complex issues and to test alternative policies that lead them to informed decisions. By understanding how systems work, students expand their time and space boundaries, gain an awareness of the effect of their own actions and personal interactions within the system. Finally, students learn interdependencies, long and short-term solutions, and that they make a difference within the system (Stuntz, Lyneis, & Richardson, 2001).

Hypothesis

Although system dynamics techniques are currently being used in K-12 classrooms, there is still a question of whether or not these techniques are effective in improving student understanding. Although there is anecdotal evidence to support the use of systems techniques in the classroom, researchers have found that empirical research conducted on the comparative efficiency of computer-assisted education and traditional instruction is limited (Chang, 2001; Costello, 2001; Costello *et al.*, 2001; Hight, 1995; Stuntz, Lyneis, &Richardson, 2001). The field of environmental education is also difficult evaluate, which has resulted in a shortage of well-controlled studies reporting classroom methodologies for environmental education (Smith-Sebasto, 2000). This study hopes to close the gap between the anecdotal and empirical evidence.

This study compares the effectiveness of learning for two groups of students, with one receiving a traditional lecture and the other receiving a lecture that utilizes system dynamics. I hypothesize that the students receiving the lecture with system dynamics concepts will meet the standards of the NDOE, have a better understanding of the material, and will retain the information longer, because they will understand the dynamics of the processes through the hands on use of system dynamics models. The amount of learning for these students, shown by scores on the posttest compared to the pretest, will be higher.

Method

In order to compare the effectiveness of learning about wetlands systems through system dynamics models versus traditional methods, I have created system dynamics models of basic wetlands processes (Figures 1 & 2). These models include the important components of wetland systems: water, plants, and animals. Kainz and Ossimitz (2002) found that even a short intervention of 90 minutes that introduce basic concepts about stock and flow diagrams improve students' performance on subsequent tasks. This study found that students with the intervention introducing basic system dynamics concepts performed better than similar students in the Sweeney & Sterman (2000) and Ossimitz (2002) study with similar students. This study will analyze if the results of Kainz and Ossimitz (2002) translate to other studies.

Objectives for presented content and assessment questions were developed based on Bloom's Taxonomy (Bloom, 1956). Using these objectives about the WPNP, the powerpoint instruction of Stave *et al.* (2003) was analyzed for relevance. Each slide of the presentation were either reworded or discarded if not applicable. Fourth graders from the Clark County School District were recruited. Teachers who are implementing systems thinking into their classrooms found that at the 4th grade level, students have trouble with writing, reading, speaking, listening, working with others, and developing self-esteem (Brown, 1992). Also, the majority of schools in the United States begin to have children work on more complex tasks after third grade (Draper, 1993). Due to these factors, some researchers believe that the optimum time to introduce systems thinking at the 4th grade level, then work up through the middle school and into high school (Brown, 1992). Participants will randomly be assigned to one of the instructional treatment groups, either traditional or simulation-based. The treatments differed only in how students will be taught about the WPNP. In the traditional group, students will be presented with a lecture format powerpoint slides. Students in the simulation-based group will work with the hands on activities and the models. Treatment sessions will follow the same format and time length. All treatments will be taught be the same instructor to eliminate any effect different speakers would have.

Subjects

Subjects for this study will include fourth graders from the Clark County School District. Students will be placed in groups without any knowledge about the different treatments. Both groups will be held at the same time and day in different weeks.

Testing Procedures

Students will be administered an evaluation instrument before, immediately after, and 2 weeks after instruction. Questions will be categorized into 6 topic areas so that analysis could evaluate how much learning has occurred in the different areas of the objectives.

Evaluation Instrument

Klein (1972) found that multiple-choice items are appropriate to elicit the behaviors according to Bloom's taxonomy (Bloom, 1956), except for the synthesis level, which requires students to write their own responses to questions.

Questions will be grouped into categories of both topic area and difficulty level. Questions on the testing instruments were placed into the first three levels of Bloom's Taxonomy, knowledge, comprehension, and application (Bloom, 1956.). The knowledge category will include questions involving recall of presented information. Comprehension questions will force students to draw on their understanding of concepts and interconnections. Application requires the student to understand the big picture and be able to apply new material not covered or discussed in the instruction.

Testing with Groups

This study uses a pretest-posttest control-group design (Chang, 2001, Çepni *et al.*, 2004; Kainz & Ossimitz, 2002; Roberts, 1976; Roberts, 1978). Pre and posttest are given and analyzed in order to compare the effectiveness of learning with system dynamics versus using a powerpoint lecture.

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