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How System Simulations Improve Student Learning by Assisting in the Creation of Clear Mental Models

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Abstract

Tests were conducted with a fish farm system simulation in combination with other activities in order to measure its effectiveness as an aid in teaching and learning about water chemistry and eco systems. Results support the dual coding hypothesis (Paivio, 1990) that posits two kinds of connections: representational connections between verbal stimuli and verbal representations, and between visual stimuli and visual representations and referential connections between visual and verbal representations. (Mayer/Anderson 1991) Seventy-six students from three New York City private and public schools participated in the study. The research design used a quasi-experimental pre-test-post-test non-equivalent control-group design (Gall et al., 1996).

Introduction

A major goal of science is to provide explanations for how various physical, biological, and social systems work. (Mayer/Anderson 1991) Learning occurs when learners actively construct meaningful mental representations from presented information. (Mayer 1999) Our hypothesis states that if an interactive fish farm system simulation were created in the proper presentation format, students could develop a better understanding of how to manage the complex water chemistry when running a real fish farm. That system simulation would allow the student to not only control the speed of the animation or simulation, but also allow that student to change the various parameters of the system in order to see the consequences of those manipulations on the system. For example if the student dumped 70% of the water in the system and forced a drop in water temperature of more then 20 degrees all of the fish would die and float to the top of the tank. The fish farm simulation would assist in the creation a clear mental model of how the eco system in the fish farm worked. The system simulation would create the mental model and the hands on activities in the real world fish farm and would re-enforce this knowledge, which would last longer in short and long term memory. (What Mayer 1999, called internal connections) and then integrating them with one another and prior knowledge to what (Mayer 1999 called external connections) The live fish farms in the classroom re-circulation systems as well as the large fish farm at the remote location.

Studies of using still image and animations in education have been going on for many years yet much of the reported results has either been inconclusive or challenged a needed to be revisited. Papert 1990,Mayer/Anderson 1991, Hatfield/Bitter 1994. Tversky 2002 revealed that although animation was revered as more effective in student learning the still images a closer review illumined the fact that with out the ability of the end user to control the speed of the animation frame rate much of the information passed by so fast the student was unable to process it. In 2005 Chan/Black built and tested a presentation format-direct-manipulation animation (DMA), which, allowed the end user to completely control the speed of the animation and the research data proved this as an effective presentation format for learning on comprehension. Dorward, J., & Heal, R. (1999) proved a solid case for the use of java applets or "virtual manipulative" were the students fully controlled the input of variables as effective learning tools in mathematics.

The fish farm system simulation was built to complement the "Young McDonalds Farm Project" which we had been involved in since 1997. Ocean of Know Fish Farm simulation (Black, Greiner, McVeigh, Ortiz, Wallace 2005) The fish farm simulation is designed to teach Mathematics-parts of a whole number and scientific measurement. This project is housed in the Rutgers University Eco Complex research greenhouse in Columbus New Jersey.

All "in classroom fish farm hands on activities" were left in the program and included in the research and data gathering phase as they gave students the real world experience. We intended to show by using the fish farm simulation coupled with the hands on activities that by engaging students and teaching them how systems work, it would be easier to teach them science and mathematics skills. Other educational theorists advocating the adaptation of instruction to mimic human development and deriving knowledge from experience include Froebel (1782-1852), known as the founder of kindergarten, Herbart (1776-1841), Dewey (1859-1952), and Montesssori (1870-1952) (Sobol, 1998) Sowell (1989),

Last, we conducted an empirical study with seventy-six students from three New York City private and public schools to try and help them better understand how eco systems/fish farms worked to evaluate the effectiveness of the student controlled system simulation for short term and long term memory, and knowledge transfer. Our research results help us further develop a human computer interface design that will provide students with a place for a live subject of study.

Education potential

According to. (Pea, 1997) many advancements have been made in scientist visualization however these tools have been designed and built to help professional scientists not students in middle school or High school. The tools we need to design for students will help them to learn very basic scientific concepts and methodologies. Water chemistry plays a major role in the functioning of an auaponics system. In cases like these, animations reflect an experts constructs and theories about a phenomenon. They become animations of thought. D. Schwartz, Blair, Biswas, Leelawong, Davis, 2005 Moving from a presentation format-direct-manipulation animation (DMA), which, allowed the end user to completely control the speed of the animation Chan/Black 2005 to a system simulation which students can not only control speed and time but also manipulate the system by inputting variables which include but are not limited to: pH, temperature, and ammonia levels and then allows the end user to see the consequences of those actions on the system.

This fish farm simulation is partnered with real world hands on aquaculture activities and open conversations with expert scientists. The project shows potential for the teaching and learning of basic scientific concepts to Middle and High school students.

Problems with Animation and the potential of virtual manipulatives

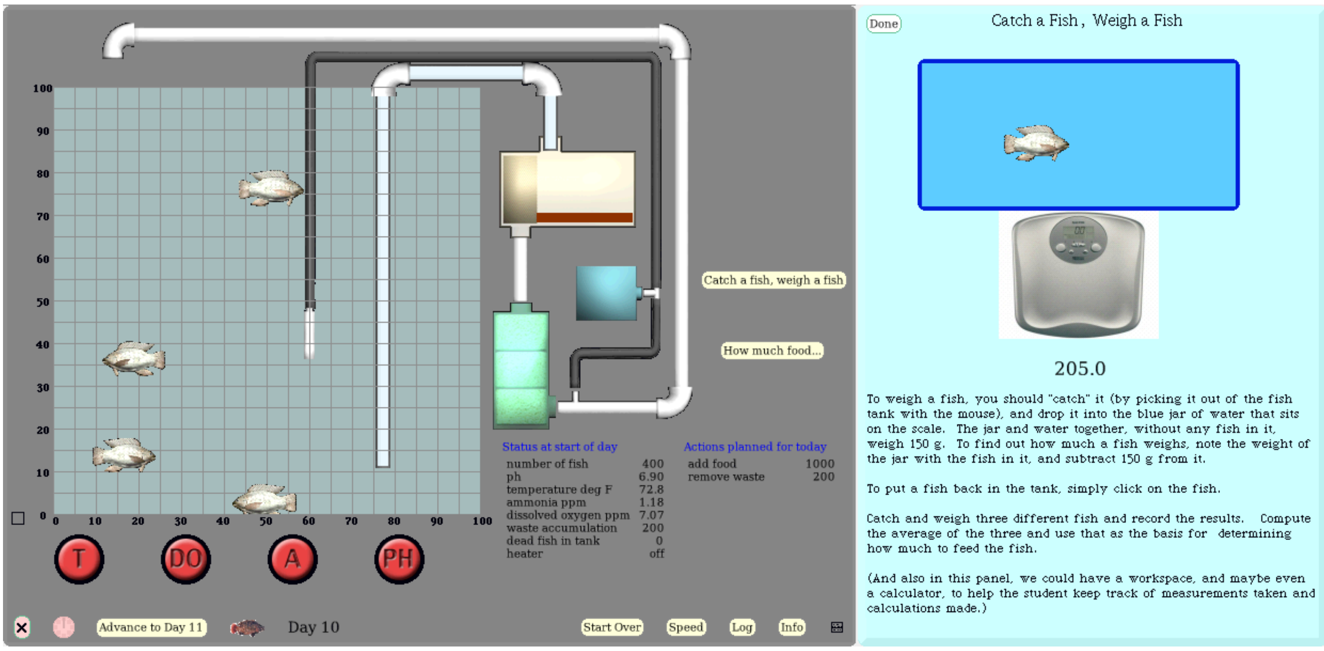
Earlier revealed that the animations captured student's interest however since students could not control the frame rate of the animation they played the animation over and over in order to observe how the system was working (Black, McVeigh 2003). Viewing the animations and hearing the verbal explanation helped create and contribute to the knowledge base about how the system worked. However, it was during the construction phase where students fully developed clear mental models of how the system worked. Although the students in Group 1 who viewed the animations were able to build the system significantly faster then the students who did not, full comprehension of how the system worked would not have been achieved if they were to have viewed the animation without the system construction phase. Research by Tversky 2002 immediately explained why students were spending so much time reviewing the re-circulation fish farm animation over and over again. Students had no control over the speed of the animation frame rate and so needed to constantly review the animation to understand the flow of the system.

Although many are enthused about the great potential for using animation in education, there can be disadvantages of viewing an animation, which traditionally runs at 30 frames a sec. If a student is trying to better understand how a system works and has no way to slow down or even stop the flow of the animation frames it may not be possible for the student to actually see the function of the parts of the system because those parts are moving to rapidly for the human eye to see and then process that information into working memory. Tversky 2002. In 2005 Chan/Black built and tested a presentation format-direct-manipulation animation (DMA), which, allowed the end user to completely control the speed of the animation of a roller coaster for backward or forward motion in order to better explain the concept of potential and kinetic energy. The data concurred with their hypothesis, which proposed that comprehension and learning would be enhanced if the presentation format supports what the learners need to construct a dynamic mental model of the referent phenomenon. Research by Jan, L. Plass, 1997 who studied the use of images sound and video clips in the area of language, showed that they played an important role in vocabulary acquisition and in overall text comprehension for English language learners. Dorward, J., & Heal, R. (1999) proved a solid case for the use of java applets or "virtual manipulative" were the students fully controlled the input of variables as effective learning tools in mathematics. Dorward, J., & Heal, R's research and development of the National Library of Virtual Manipulatives (MLVM) was so impressive Black, McVeigh evaluated these virtual manipulative in the NYC public schools in 2003, 2004 and 2005 and found the virtual manipulatives be to effective tools for helping students to better understand fractions at the fifth and sixth grade levels. We decided to build and test a fish farm system simulation in order to help students better understand how eco systems work more specifically aquaculture.

Context-Hypothesis

Based on our current understanding of how students view and process visual, tactile, and audio information, how human memory works, as well as how near and far knowledge transfer functions we propose the following presentation formats Our hypothesis states that if an interactive fish farm system simulation were created for the fish farm where students could attain a better understanding of how to manage complex water chemistry they would perform much better when running a real fish farm. That system simulation would allow the student to not only control the speed of the animation or simulation, but also allow that student to change the various parameters of the system in order to see the consequences of those manipulations on the system. For example if the student let the pH level drop to 5.00 for more then a few days fish will start to die off in the system and float on the top of the tank.

A more positive example might be a student who is careful to maintain proper temperature, pH and ammonia levels will see their fish grow large and gain weight as the days progress. The fish farm simulation would create a clear mental model of how the eco system in the fish farm worked and that knowledge would transfer to the real world project in short term and long term memory. The system simulation would create the mental model and the hands on activities in the real world would re-enforce this knowledge that would last in short and long term memory. (What Mayer 1999, called internal connections) and then integrating them with one another and prior knowledge to what (Mayer 1999 called external connections) The live fish farms in the classroom re-circulation systems as well as the large fish farm at the remote location. In the classroom at the local location students will build a 20 gallon re-circulation fish farm system and fill it with tilapia fish, one grow lamp, four one gallon jugs of water with air stones and hydrosol fertilizer with plants for hydroponics set ups and one robotic arm kit in the real world. Students learn more from building objects then they actually do studying them, (Papert 1993 Computer based Fish farm simulations will be loaded on to at least 30 laptop computers, which students had have access to. This fish farm simulation is key to helping the students better understand theories about water chemistry phenomenon that, affect the entire living system. . D. Schwartz, Blair, Biswas, Leelawong, Davis, 2005. The school will have a video over ip video conferencing system set up for greenhouse video links and robotic control. Young McDonald's Farm a hybrid model for online education provides 1) live video links to the fish tanks and plants in the remote greenhouse with a science expert available to answer any questions students may have; 3) remote sensors that monitor the aquaculture and aquaponics environments in real time. 4) Telerobotics, which will provide the end users with the ability to remotely manipulate and control the live system, which is housed in the Young McDonald's Farm greenhouse.
In the present empirical study, the learners received a short ten-minute explanation of the fish farm simulation and were then asked to run the fish farm until day 30 (each day was five seconds). Students need to write down their measurements of ph, Temperature, ammonia and fish weight every five days. If students killed off all of their fish to soon they simply rest the simulation and started over. Our expectation was that students would start to understand the consequence of extreme pH, temperature or ammonia levels. After all of the student groups of 4 had reached day 30 the class held an open Q and A session where students shared their results of maximum fish growths or many fish deaths due to wild pH levels or high ammonia rates.



fish farm system simulation

Major research questions

We wanted to compare students understanding of how systems worked when they received different types of instruction. A major goal of science is to provide explanations for how various physical, biological, and social systems work. (Mayer/Anderson 1991) Constructivist learning occurs when learners actively construct meaningful mental representations from presented information. (Mayer 1999) If interactive fish farm system simulations were created for the fish farm where students could better manage complex water chemistry in a real fish farm after working with the simulation? (What Mayer 1999, called internal connections) and then integrating them with one another and prior knowledge to what (Mayer 1999 called external connections) The live fish farms in the classroom re-circulation systems as well as the large fish farm at the remote location.

The two major research questions were:

• Will a fish farm system simulation help students to better understand the consequences of water chemistry specifically temperature, pH and ammonia levels in aquaculture and short term and long term memory?

• Will students experience a short term and or long-term transfer of knowledge between using the virtual fish farm and then managing the real fish farm?

Empirical Studies
Method
Seventy-six students from three New York City private and public schools participated in the study.
The research design used a quasi-experimental pre-test-post-test non-equivalent control-group design (Gall et al., 1996). This method is the most extensively used quasi-experimental design in educational research (Borg & Gall, 1989). The model is referred to as quasi-experimental because of the nonrandom assignment of subjects to groups. Students in two treatment groups, hands on activities (HOA) and System simulations (SS), remote links (RL) will be compared to students in a traditional instruction (TI) control group with hands on activities but without the use of system simulations or remote greenhouse links. Understanding water chemistry in an eco system was the focus of the research topic because concepts of temperature, ph, and ammonia levels posed great difficulty for students to understand.

Procedures
Before any of the activities started all of the students were asked to draw a diagram of a fish tank which explained how the system worked which, allowed us to evaluate any prior knowledge. (15 Minutes) All students were asked to tell the group of students they were with what they new about raising fish or explain how a fish tank system worked. (15 minutes), All students were visited once a week for eight weeks.
All student groups participated in the assembly of their fish farm tank/eco system. (45 min or one class period) Two weeks later all of the students received tilapia fish
All students were given and oral quiz (10 minutes) with a questions about water chemistry and system management problem to solve, for example "What would you do if you tested the fish tank and the pH level jumped to 9.5? And scored with a rubric and all students were required to make a diagram of how the fish farm worked at the end of the sessions.
Students received traditional instruction on aquaculture and hydroponics over that time period. Lessons included: How to set up the fish farm, pH, The affect of temperature on tilapia fish, basic water chemistry testing, fish math-fractions decimals and percents, catch a fish weigh a fish, hydroponics, dissolved oxygen.
Group 1 - System simulations (SS) remote links (RL) hands on activities (HOA)
Had the fish farm system simulation session (SS) once for forty-five minutes before they set up their fish tank. They then made five forty five minute video conference calls to the greenhouse for open question and answer periods. - Remote links (RL)
Group 2 - System simulations (RL) hands on activities (HOA)
Had the fish farm system simulation session (SS) once for forty-five minutes before they set up their fish tank. hands on activities (HOA). **Group 3** hands on activities (HOA) **only**

Results and Findings
Tallying the number of correct basic system questions scored the oral quiz
Tallying the number of correct problem solving questions scored the second oral quiz
Counting the number of properly labeled system parts and functions scored the system diagram.

Table one shows the mean scores and standard deviations of the system oral quiz, problem solving oral quiz, and the system diagram tasks for each group. Based on independent tests Group 1 and Group 2 out preformed Group 3 on the problem-solving test however stayed with in the same range of the basic system quiz and the system diagram.

*Note System simulation (SS), remote video links (RL) hands on activities (HOA)
System Quiz: (SS) (RL)(HOA) *(M=93.5),* (SS) (RL) *(M=91.1)* (HOA) *(M=81.8)*
Problem solving questions (SS) (RL)(HOA) *(M=91.2)*, (SS) (RL) *(M=90.2)* (HOA) *(M=43)*
System diagram (SS)(RL)(HOA) *(M=99)*, (SS) (RL) *(M=95.3)* (HOA) *(M=87.2)*

Group	System oral quiz	Problem solving questions	System diagram
	M	M	M
(SS) (RL)(HOA)	93.5	91.2	99
(SS) (RL)	91.1	90.2	95.3
(HOA)	81,8	43	87.2

*The (SS) (RL)(HOA) group and the (SS) (RL) group scored significantly better then the (HOA) group.
**The (SS) (RL)(HOA) group and the (SS) (RL) group scores showed little difference.

The findings corroborated the hypothesis since Group 1 (SS) (RL)(HOA) and Group 2 (SS)(RL), fully developed clear mental models of how the system worked after only one 45-minute session with the fish farm simulation. Will a fish farm system simulation help students to better understand the consequences of water chemistry specifically temperature, pH and ammonia levels in aquaculture and short term and long term memory? Students who used the simulation were first quizzed on the effects of temperature, pH, and ammonia the same day. (Short-term memory) Students were not only able to give correct answers to questions like: What is the safe pH range for tilapia fish? A: The safe range is 6.5 to 7.0. But were also able to answer the problem solving questions with out hesitation: Q-What would you do if the pH level jumps to 9.5? A: -Add sodium bisulfate Q: What would you do if the ammonia level jumps to high? A: dump 30% of the water in the tank and replace it with clean water.

Observations in the classrooms two months later (Long-term memory) proved that students were able to manage their real fish farm with the knowledge they had gained from using the fish farm simulation. One example comes from Group 2 (SS)(RL) Students had observed two fish deaths after coming back to school over a long weekend. The students immediately started to investigate the cause of death in order to determine if the other fish might be at risk. Several students formed a hypothesis of pH levels being off and several other students took a position that the ammonia levels had be come toxic. Water test were done with a La Mote water quality test kit. Student data showed that the pH level appeared to be with in the safe range however the ammonia levels were high. To correct the problem students knew to dump 30% of the fish tank water and replace it with the emergency gallons of spring water, which were in the classroom.
This answered our second question: Will students experience a short term and or long-term transfer of knowledge between using the virtual fish farm and then managing the real fish farm?

Helping students to understand how pH and temperature effect a living eco system in prior middle school science classes proved to be a challenge, however when students used the fish farm simulation not only were students aware of monitoring temperature and pH in their systems but showed keen awareness of ammonia levels which in past lesson was simply unheard of. This data shows great promise for a better method of helping students to better understand more complex systems. Group 1 was the only group who participated in the greenhouse video links. The learning context for the live video links with the fish farm was and open forum for questions and answers about plants and fish with a qualified system specialist in aquaponics. Students took to this opportunity instantly. Teachers were forced to end each 45-minute session because the students never seemed to run out of questions about aquaculture or hydroponics. It was in this forum that students learned a substantial amount of information about how systems worked then the other groups. The additional knowledge was evidenced in their oral quizzes.

"Understanding is more likely to occur when a student is required to explain, elaborate, or defend his or her position to others"- Brown and Campione 1986 Group three was the lowest performing group students. Although students mathematic skills showed a better understanding of fractions, decimals, and percents were quizzed on their diagrams they could name the parts of a fish tank but had little understanding of what they did and really had no understanding of how temperature, pH and ammonia affected the fish farm system.

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Note*The CoVis project, is a telecommunications “Collaboratory” or online teaching laboratory that was established by Lederberg & Uncapher and funded by NSF in1993.

Ocean of Know is a telecommunications “Collaboratory” or online teaching laboratory
that was established by McVeigh, Chieu, Fico, and McClintock 1993
and funded through private donations.
Ocean of Know Fish Farm simulation (Black, Greiner, McVeigh, Ortiz, Wallace 2005)
(The fish farm simulation is designed to teach Mathematics-parts of a whole number
and scientific measurement).

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