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AUTHOR	Cherry, Gina; Ioannidou, Andri; Rader, Cyndi; Brand, Catharine; Repenning, Alex
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ABSTRACT

Computer simulations are one promising tool for supporting learning at all levels--from elementary school to workplace learning. Learning through simulations, either by creating simulations or by exploring existing ones, helps learners develop a deeper understanding of the concepts being simulated. Learning about simulations is also important since simulations are frequently employed to make predictions or test ideas by scientists and policy makers. This paper describes a number of simulations that have served as tools for a variety of lifelong learners, ranging from elementary school students to professionals. These simulations were all created with the Visual AgenTalk language (VAT) employed by the AgentSheets system. (Contains 18 references.) (Author/AEF)

Simulations for Lifelong Learning

Gina Cherry
Department of Computer Science
University of Colorado—Boulder
gina@cs.colorado.edu

Andri Ioannidou, Cyndi Rader, Catharine Brand, Alex Repenning
Department of Computer Science
University of Colorado—Boulder
andri, crader, brand, ralex@cs.colorado.edu

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Abstract

Computer simulations are one promising tool for supporting learning at all levels—from elementary school to workplace learning. Learning through simulations, either by creating simulations or by exploring existing ones, helps learners develop a deeper understanding of the concepts being simulated. Learning about simulations is also important since simulations are frequently employed to make predictions or test ideas by scientists and policy makers. In this paper, we describe a number of simulations that have served as tools for a variety of lifelong learners, ranging from elementary school students to professionals. These simulations were all created with the Visual AgenTalk language (VAT) employed by the AgentSheets system.

Introduction

In recent years, there has been much discussion about how technology can best be used to support learning. Computer simulations are one promising tool for supporting learning at all levels—from elementary school to workplace learning. Learners may create simulations in order to test hypotheses and explore ideas, or to communicate their ideas about a topic to others (Repenning, Ioannidou, & Ambach, 1998). Exploring simulations created by others exposes learners to ideas that may be different from their own, and gives them an opportunity to experiment with those ideas. Learning through simulations, either by creating simulations or by exploring existing ones, helps learners develop a deeper understanding of the concepts being simulated. A recent study by the Educational Testing Service (Wenglinsky, 1998) found that students in classes which used computer simulations to teach mathematics made significant gains on standardized tests, and scored significantly higher on standardized tests than did students in classes where computers were used for "drill and practice."

Learning about simulations is also important for lifelong learning. Simulations are frequently used as tools by scientists and policy makers. These simulations are based on simplified, imperfect assumptions. In order to be able to interpret and question these simulations, one must understand how simulations are constructed (Starr, 1994; Turkle, 1997). Working with simulations from an early age can provide a foundation for this sort of "simulation literacy."

In this paper, we describe a number of simulations that have served as tools for a variety of lifelong learners, ranging from elementary school students to professionals. These simulations were all created with the Visual AgenTalk language (VAT) employed by the AgentSheets system (Repenning & Ambach, 1996).

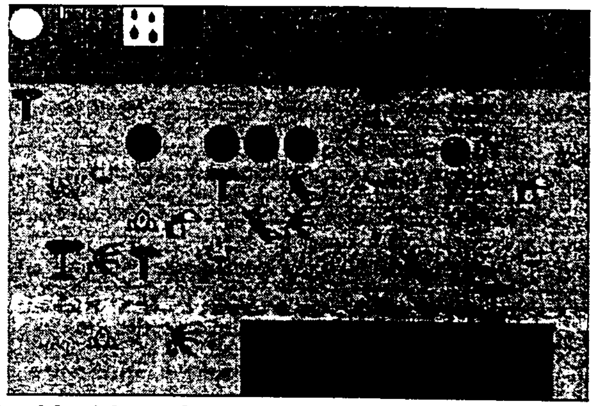
Elementary Schools: EcoWorlds

Current reform efforts in science education emphasize constructivist pedagogies (Yager, 1995)—approaches that place students at the center of the sense-making process and suggest that students learn by actively building their own understanding of a topic. One promising approach to meaningful learning and robust understanding of science centers on the creation and use of computer simulations as representations of how and why things work (President's Committee of Advisors on Science and Technology, 1997). Activities with simulations have the potential to help children organize, develop, test, and refine their ideas about science.

As part of the Science Theater/Teatro de Ciencias (sTc) project (Carlone, Garcia, & Lewis, 1998), we have developed a number of activities with simulations for elementary school students. The EcoWorlds curriculum for 4th and 5th graders is the culmination of three years of research on how children can build simulations of scientific phenomena, first using Cocoa (Brand & Rader, 1996; Cypher & Smith, 1995; Rader, Brand, & Lewis, 1997), and later Visual AgenTalk (Lewis, Brand, Cherry, & Rader, 1998). EcoWorlds focuses on a number of content areas, including characteristics of organisms, structure and function in living systems, populations and ecosystems, and diversity and adaptations of organisms. The unit addresses these issues by having students work in small groups to create computer simulations of ecosystems in different environments such as the Arctic or a desert. Activities with simulations are integrated into a curriculum which incorporates hands-on activities, research activities, and class discussions.

Students initially meet in small groups to discuss what types of animals might be found in their chosen environment. Each student then designs an imaginary animal which could be native to that region. The animal design must include adaptations for the animal to survive the temperatures common to its environment as well as to mate and to acquire food. Within each group, students collaboratively work out the predator-prey relationships for their ecosystems.

One group of students in the class decided to create an island ecosystem. Students created a food web for their ecosystem which included a bird, a reptile, and two amphibians. They designed their animals by first entering "features" for the animal and brief explanations of how these features helped the animal survive. Students generated their own ideas for features rather than choosing from a predefined list. For example, Laura's animal, the "purple whippy frog," is a small, plant-eating amphibian. Laura gave her frog a number of features to protect itself from predators, including fast legs to "get away from predators," poisonous skin to "protect itself," and slimy skin "so it does not get stuck." She also gave her frog some features which allow it to eat plants, including grindy teeth "to chew" and bacteria stomach "to help digesting."



Island EcoWorld with student-created birds, amphibians, and reptiles

Although they use a visual programming language (Visual AgenTalk) to create their animals, our primary goal is for students to learn about science, rather than to learn how to program. We have therefore modified the programming language extensively to make it more natural for students to express their ideas while maintaining a focus on the important science concepts (Rader, Cherry, Brand, Repenning, & Lewis, 1998).

In EcoWorlds, students "program" their animals using commands which relate specifically to the science content. When students create a new animal, they essentially fill out a form or "template" which provides the basic structure for the animal's behavior. These templates help them focus on the science content by taking care of the numerous non-science details which would be required to create an ecosystem simulation from scratch. The templates also provide constraints on animal designs by building in feedback. For example, an animal will die if it does not get enough food to eat or if the environment is cold and the student has not given the animal adaptations to survive the cold. Thus, students must think about science issues which otherwise might not have occurred to them.

The collaborative nature of creating an EcoWorlds simulation also pushes students to think more deeply about science concepts. Students were told that each animal must either eat or be eaten by at least one animal created by another student. In the process of negotiating the predator-prey relationships, students had to justify their ideas about their animals to one another. Because the predator-prey relationship is expressed as a conversation between two animals, students had to design the features of their animals to work together. In the island group, for example, the sharp beak of the Guglle-Buglle bird lets it eat the Squirm reptile egg, which has a leathery covering.

Once students had tested their individual animals, they performed experiments on their entire ecosystem to see whether all the species they had created could survive over time. An experiment in EcoWorlds consists of placing plants and animals into the simulation, running the simulation for some number of days, and observing changes in the populations of the different species. Elementary school students require assistance in order to be able to effectively experiment with simulations. The curriculum was designed to help students understand the goal of the simulation, as well as set up experiments, make and record predictions, run experiments, analyze the results, and make adjustments to the simulation based on experiments.

The abstract concept that a change in a single plant or animal population may affect an entire ecosystem is a difficult idea for 4th and 5th graders. EcoWorlds makes this concept more accessible to students by offering them an opportunity to experiment with a dynamic visual model. Students were encouraged to think of different ways to set up their experiments. For example, some students thought it would be best to use the same number of animals from each species, whereas others knew that their ecosystem would require more animals of some species than of others.

Students often encountered unexpected results while running their simulations. They observed population changes, noting when a species became extinct or overpopulated, and were able to suggest ways to avoid these occurrences—varying the initial numbers of animals in the simulation or revising characteristics of their animals, such as their likelihood of mating or catching their prey.

Students were very engaged in this task, in part because of their identification with the animals which they created. They referred to their animals in the first person, saying for example "I'm dead" rather than "My animal is dead," or "I can eat you" rather than "my Ozzie can eat your Purple Whippy Frog." Because of this identification, students were very motivated to ensure that their animals survived. Although students initially had a tendency to want their animals to survive even at the expense of other populations, this tendency was often overcome once they realized that the other species were necessary for their animal's long-term well-being.

Our work with EcoWorlds has addressed some of the challenges we found in our previous efforts (Brand, Rader, Carlone, & Lewis, 1998; Lewis, Rader, Brand, & Carlone, 1997). In particular, by integrating the simulation activities with other activities (hands-on, research, discussions) and by modifying the software to be more content-specific, we have created a curriculum in which students are much more successful at creating their own simulations and in understanding the underlying science concepts. With the appropriate support, elementary school students can use simulations as a vehicle for new understanding and insight.

High Schools: The Grape Boycott

At the high school level, John Zola's students used simulations as part of the "Protest and Reform" history class at New Vista High School (Ioannidou, Repenning, & Zola, in press). In this class, students had an opportunity to study protest movements throughout U.S. history (e.g., the Civil Rights movement and the anti-Vietnam war movement), and to learn about theories of protest and social change. Initially, the teacher used "Segregation" (Schelling, 1971) and "Protest March" simulations created by researchers to present some basic ideas about protest and reform. Later in the course, students created their own simulations to present their thoughts and ideas for their final projects.

One of the groups that chose to do a final project using AgentSheets consisted of four girls who were initially intimidated by technology. They selected the topic of the California Grape Boycott in the context of the Chicano/a, Latino/a Civil Rights movement. The project, as the students defined it, included building a Web page which consisted of a boycott simulation applet which they had created, as well as links to related Web sites. The students intended their Web page to serve as a small virtual library on the subject.

The students realized that they needed to find out about the history of the boycott and of the United Farm Workers movement in order to begin building the simulation. They did some initial research in the library and on the Web to learn the basic historical facts, and found relevant Web pages which they referenced on their own Web page.

Once the students understood the basic facts about the boycott, they began to create their simulation. Presenting a complex social phenomenon such as the boycott without making the simulation overwhelmingly complex was a challenging project for these teenagers. Their first task was to choose a representative set of events that could be simulated. The students decided to illustrate the relationships among all the people involved in the boycott: farmers, workers, consumers, and worker organizers. Consequently, they created a simulation which represented individual people such as workers picking grapes, farmers that own the grape fields, consumers buying the grapes at the town's market, and Cesar Chavez influencing the consumers to participate in the boycott.

The process of building the simulation, running it, and observing the consequences led to new questions. When the students programmed the workers to get angry and refuse to work, the result was confusing. What really happened? How could there be grapes in the market when the workers were on strike? To answer these questions, the students went back to historical sources. They learned that when the Mexican and Filipino workers went on strike, farmers hired illegal immigrant workers. The students added information to their simulation in order to reflect this new piece of knowledge. In this case, building the simulation provided a focus for group discussion which pushed the students' ideas beyond their initial conceptions.

As these high school students developed the boycott simulation, they also created Web pages (http://www.cs.colorado.edu/~l3d/systems/agentsheets/New-Vista/Boycott-Project.html) containing historical information about the subject and links to related Web sites. These Web pages provide a critical connection between the course content and the simulation technology—a simulation consisting of brightly colored icons moving on a screen does not convey much meaning to its intended audience unless the creators of the simulation situate it in an informative context.

Collaboration also played an important role in this project. Initially intimidated by the computer, students found the task of creating a simulation less daunting when they all worked together, sharing ideas and helping each other out with the programming. The dual tasks of creating the Web site and building the simulation allowed members of the group to distribute the workload among themselves according to their individual interests. In this case, collaboration allowed the group to create a more complete project than any individual could have produced alone.

Creating simulations is a valuable experience for students when they use it as a way of story telling. Through this story telling, they gain a deeper understanding of the simulated subject. In the boycott project, the students had to learn about the history behind the Grape Boycott at a level of understanding that went well beyond that of typical high school projects. When building simulations, students do not have the option of mindless cutting and pasting of information as they do when they create a posterboard or a report. To create a simulation, students must form a deep understanding of the underlying principles of the topic. They must decide which aspects of a phenomenon or scenario are most significant and worth simulating. After discarding the less significant details, students must choose representations for the simulation actors and decide on rules which represent the behavior of individual actors as well as the relationships among actors. All these tasks demand a significant intellectual effort by students.

The high school students themselves became aware that creating simulations helped them learn about the boycott in a different way, as illustrated by their remarks:

> ***Clara:*** *"I didn't know anything about the boycott before. Having to apply it to the technology made me get into it more and understand it fully so that I could have it come out correct."*
>
> ***Teacher:*** *"More so or differently so than if you had created a posterboard?"*
>
> ***Susan:*** *"You had to know more because you couldn't leave out things. So if you didn't know everything you couldn't do it."*
>
> ***Stella:*** *"It's not like you can copy it out of an encyclopedia and put it on the posterboard."*
>
> ***Maria:*** *"It wasn't just boring writing stuff down; we got to interact with what we were doing."*
>
> ***Stella:*** *"[making the simulation] totally made you apply what you know towards like what you're doing!"*
>
> ***Susan:*** *"I took this class just for history; I didn't know it was gonna be anything with computers, but now that I did the whole computer thing, it's changing my daily life cause I used to hate computers and now I don't."*

Simulations Outside the Classroom: E. Coli and Prozac

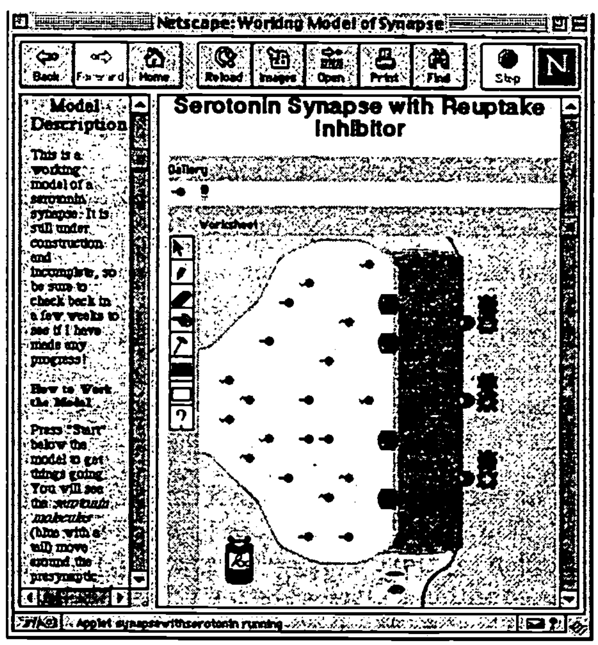
The value of building and using simulations is by no means limited to K–12 education; simulations are powerful tools for learning outside the classroom. Scientists create and use simulations both to explore and communicate complex ideas, as illustrated by the examples in this section.

Scientists often create simulations to help them test their hypotheses. Creating and experimenting with such simulations can give scientists new insight, help them revise their hypotheses, and help them predict the results of potentially expensive experiments.

In one example of this use of simulations, scientists at the BioServe Space Technologies have created a simulation of the behavior of E. Coli bacteria in low gravity settings in order to explore the implications of this behavior for fermentation biotechnology (Klaus, 1998). Scientists had previously found that fermentation occurred more quickly and with better results in space, but had not been able to explain why this is so. The goal of the simulation is to explain why E. Coli bacteria behave differently in low gravity situations such as aboard the Space Shuttle. Understanding the faster growth factor of bacteria in space may then allow pharmaceuticals to be produced less expensively in space than on earth.

Building this simulation has helped BioServe scientists to better understand the complex molecular interactions which take place during fermentation, and to explore ideas which could not easily be explored otherwise. The physical experiments which have taken place in the MIR space station and on several Space Shuttle missions are costly and need extensive preparation. By varying parameters, such as gravity, in the simulation, and by experimenting with differing amounts of substances such as E. Coli, scientists can use the simulation to select the most promising experiments to actually conduct in space. The simulation also allows scientists to simulate cases which are outside the range of what could happen in a physical experiment.

Working with simulations can also give scientists new theoretical insights. In one example, scientists found that the results from the simulation sometimes differed significantly from the results of the same physical experiment. This difference indicated a gap in scientists' theory of how the process worked. By analyzing the divergent data, scientists were able to add to their theory about E. Coli behavior—they hypothesized that the difference could be explained by the fact that E. Coli behave slightly differently when they reach the bottom of the test tube.



Simulation running in a Web page explains how serotonin works in the synapse and how antidepressants affect the system.

Scientists also use simulations as a way of communicating complex relationships to others. In contrast to the simulation described in the previous section, which was used primarily to explore effects that were unknown to its creator, simulations for communication are geared more towards simplifying complex dynamic processes in order to explain them to non-experts. Although simulations used for communication may not provide new insights to their builders, they can be a means to learn how to communicate about an area of expertise, or a tool, to help the expert clarify his or her own knowledge about a topic. Creating such simulations requires the builder to create realistic relationships among components of the simulation. This process may also illuminate the underlying assumptions held by the builder by impelling him or her to create concrete representations of the actors in the phenomenon being simulated, and to decide which relationships are most important. Thus, simulations which are designed to teach a set of concepts can provide learning opportunities for both their creators and their users.

SimProzac is an example of an interactive simulation used primarily for communication. SimProzac was created by a psychiatrist who wanted his patients to understand the effects of Prozac on the functioning of the brain. He decided to create an interactive simulation for his patients so that they could explore the relationships among Prozac, the neurotransmitter serotonin, and neurons, in a way that would not be possible by simply reading about these relationships. Users of the simulation can observe the relationship between serotonin and neurons in the absence of Prozac, and can release Prozac into the simulated synapse at their own discretion to observe its effect on the system. The psychiatrist has embedded his simulation applet in a Web page which includes a description of what occurs in the simulation. This Web page can be accessed at http://www.csn.net/~wphillip/Synapse_applet/synapse.html.

Conclusions

For both students and adults, simulations provide an opportunity to work with ideas. In the case of students, a simulation is most often a tool to grasp ideas which are already "known" to the professional community but which are difficult to understand. For adults, a simulation can be a tool to extend the current knowledge within a field. Both students and adults, however, follow a similar process when working with simulations—stating a hypothesis, devising and running simulation experiments, and analyzing the results. They both interact with ideas when they view and attempt to explain simulation results, especially when the results are unexpected. Students who create their own simulations share with adult professionals the additional tasks of deciding what factors are most important and how to represent their understanding of the simulation topic.

Working with simulations can promote collaboration among learners because the simulations are concrete and can be manipulated and discussed. The results of a simulation experiment may yield several different interpretations, which can be discussed within a group of learners. Determining how to respond to the simulation results (e.g., how to get a species to survive or how to show why grapes were still available) can be a shared creative process. The exchange of ideas among group members can enhance the meaning that learners derive from the simulation activities.

Interactive simulations accommodate a range of engagement for learners, depending on the level of interest and amount of time available. When time is limited, users may simply observe simulations created by others. The educational benefits of this type of situation are probably similar to watching an educational video clip. In a more time consuming but educationally richer mode, learners may run some number of experiments with pre-created simulations. This type of activity allows learners to explore a topic by comparing and contrasting different scenarios. When time permits, users may get a deeper exposure to the subject matter by modifying parts of an existing simulation or even building a new simulation from scratch. By working with simulations in different ways and on different topics, learners acquire the "simulation literacy" necessary for a better understanding of the purposes and limitations of simulations, and are then better able to use simulations as a tool for lifelong learning.

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