DOCUMENT RESUME

ED 444 559 IR 020 215

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TITLE	Modeling for Understanding.
PUB DATE	2000-00-00
NOTE	7p.; In: Society for Information Technology & Teacher Education International Conference: Proceedings of SITE 2000 (11th, San Diego, California, February 8-12, 2000). Volumes 1-3; see IR 020 112. Figures may not reproduce clearly.
PUB TYPE	Reports - Descriptive (141) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Computer Simulation; Computer Uses in Education; Faculty Development; High Schools; Inservice Teacher Education; *Models; Secondary School Teachers; *Teacher Workshops
IDENTIFIERS	*Model Building

ABSTRACT

This paper focuses on one method used to introduce model design and creation using StarLogo to a group of high school teachers. Teachers with model-building skills can easily customize modeling environments for their classes. More importantly, model building can enable teachers to approach their curricula from a more holistic perspective, as well as gain insights into the inquiry process and the concepts underlying their models. The model construction process served as a means of strengthening the teachers' understanding of subject area content and pedagogical principles, and these benefits extend to their students. (Contains 15 references.) (Author/MES)

Modeling for Understanding

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Abstract: The call for "using simulations and models" is nearly ubiquitous across modern science and mathematics standards and frameworks (National Council of Teachers of Mathematics, 1998; National Committee on Science Education Standards and Assessment, 1996; Project 2061, 1993). Yet, there is little specification or agreement about what "using simulations and models" means. This paper focuses on one method we used to introduce model design and creation to a group of high school teachers. Teachers with model-building skills can easily customize modeling environments for their classes. More importantly, model building can enable teachers to approach their curricula from a more holistic perspective, as well as gain insights into the inquiry process and the concepts underlying their models. The model construction process served as a means of strengthening the teachers' understanding of subject area content and pedagogical principles, and these benefits extend to their students.

Introduction

For thousands of years people have been creating models to help them better understand the world around them. Leonardo DaVinci built models of flying machines that some claim were inspired by his desire to understand the flight of birds. Sir Isaac Newton described the behavior of physical systems with sets of equations. Jacques Vaucanson built a mechanical duck that actually ingested (and eliminated!) its food (Bedini, 1964). These models not only helped their creators better understand the phenomena that they were studying, but also helped them to convey their new ideas to other people. Similarly, teachers often mobilize the power of models to help their students grasp important ideas.

An increasingly prevalent medium for building models, which enables the exploration of complex patterns and processes, is computer modeling. Like researchers who use models to investigate the spread of disease or the boom and bust cycles of industries, many educators have recognized the potential that modeling holds for developing students' understanding. In fact, the call for "using simulations and models" is nearly ubiquitous across modern science and mathematics standards and frameworks (National Council of Teachers of Mathematics, 1998; National Committee on Science Education Standards and Assessment, 1996; Project 2061, 1993). Yet, there is little specification or agreement about what "using simulations and models" means.

Certainly, simulation models are popular with kids—witness the excitement generated by SimCity (Maxis, 1989) or Civilization (Microprose, 1996)—but how can students best *learn* from models? Though it can be educational to experiment with pre-built models, a deeper understanding comes through building and manipulating models whose underlying structure is accessible (Klopfer, in press; Resnick, Bruckman, & Martin, 1996). However, creating models from scratch is far more time consuming than using models that others have constructed. Deciding whether to manipulate a pre-existing model or design and create a new model takes on special importance in the classroom, where time and technical resources are typically limited. Our research defines model building as an important component of model "use" and therefore focuses on developing ways to support teachers and students as creators, not just consumers, of simulation models.

Several common modeling programs, including Stella (Roberts, Anderson, Deal, Garet, & Shaffer, 1983), Model-It (Soloway et al.) and MatLab, enable model design and creation. Building models in these environments depends on the ability to describe aggregate changes in these systems using mathematical relationships.

StarLogo[1] (Resnick, 1994) offers an alternative approach. In StarLogo, you write simple rules for individual behaviors. For instance, you might create rules for a bird, which describe how fast it should fly and when it should fly towards another bird. When you watch many birds simultaneously following those rules, you can observe how patterns in the system, like flocking, emerge from the individual behaviors. In StarLogo, creatures, which we generically call "turtles,"[2] move around on a grid of "patches", which comprise the environment[3].

This paper focuses on one method we used to introduce model design and creation to a group of high school teachers. The teachers, who were drawn from many departments including Mathematics, English, Science, and History, had varying degrees of experience with computers and modeling—one teacher had never used a computer before the workshop. The following sections describe our method, evaluate its success to date, and suggest some reasons for that success.

StarLogo Community of Learners

Our StarLogo Community of Learners Workshops (Colella, Klopfer, & Resnick, 1999) help teachers develop the ability to create their own models in StarLogo. They experience the whole process of model building, from the conceptualization of an idea through the final implementation, analysis, and presentation of a model. Teachers with these skills can easily customize modeling environments for their classes. More importantly, model building can enable teachers to approach their curricula from a more holistic perspective, as well as gain insights into the inquiry process and the concepts underlying their models.

Workshop Organization

In our workshops, we adopted a learner-centered approach, both to engage participants in building models of personal interest and to minimize the need for lecture-based instruction about programming. We designed the Workshops to foster a playful, cooperative, creative spirit while at the same time providing adequate structure for learning how to build models. To accomplish this balance between structure and exploration, we organized the Workshops around a set of open-ended Challenges and activities that guided participants' explorations and provided the basis for critical review.

Each Challenge was a problem statement that was meant to get participants' creative juices flowing. The Challenges came with sample projects, which teachers were encouraged to explore. The Challenges and accompanying sample projects facilitated model design and construction, built familiarity with the StarLogo environment, and introduced the principles of complex systems. Here is an excerpt from a Challenge:

> ***Introduction***
>
> Environmental influences on individuals can be quite important, but individuals frequently exert a strong influence on their environment as well. For instance, beavers build dams—changing the course of rivers; people cut down forests—altering the habitat; and termites eat wood—dramatically decreasing the stability of the original structure. In this Challenge you will combine the effects of individuals on their environment with the effects of the environment on those individuals.
>
> ***Challenge***
>
> Start by thinking about new ways that the environment could change turtle [creature] behavior. You might build a world of patches that affect the turtles' position, color, or speed in different ways. To see an example of this kind of project, check out Speeding Bumper Turtles [a sample project].
>
> Of course, turtles can also change their environment. As an alternative, you might build a project that asks the turtles to manipulate the patches in their environment. Perhaps your turtles will "move" objects in the patches as in the Turtledozers or Termites [sample] projects. How do these changes in the environment in turn change how the turtles react to the environment?

After receiving the Challenge, many workshop participants spent time exploring the sample projects. These samples illustrated some of the principles of, and possible solutions to, the Challenge. Some people chose to

[1] StarLogo is available for free on the web at http://www.media.mit.edu/starlogo
[2] Admittedly, "turtles" is not truly a generic term. It comes from the "turtle" in the Logo programming language.
[3] Picture a giant chessboard with creatures moving around on it, interacting with one another and with the squares on the board.

try out these samples to get some ideas for their own projects, while others dissected these sample projects to develop a better understanding of the underlying mechanisms that produced the observed patterns. Other participants elected to address the Challenge by building their own model from scratch.

Whether or not participants chose to start with the sample projects, the open-ended nature of the Challenge encouraged a wide variety of solutions. Workshop participants chose to investigate and apply aspects of StarLogo that were relevant to their own interests and concerns, and in so doing they created projects that reflected their interests and concerns. The diversity of solutions is evident in the following projects constructed in response to the Challenge that we described. These are just three of over twenty projects that we received, no two of which were alike.

Convection

This project models the process of heating and cooling. The different colored patches cause the "molecules" to heat up or cool down. When a molecule is on a red patch (on the bottom of the beaker) it gets warmer. In fact, the more "red" a patch is, the more it heats the molecule. Conversely, blue patches (on the top) cause the molecules to cool down. Hotter molecules rise to the top, and cooler molecules sink to the bottom where they are reheated, resulting in a convection current. In the sample (Fig. 1a) the hotter molecules are seen rising in the center.

Tortoise and Hare

This project is based on Aesop's classic fable of the tortoise and the hare. The tortoise and the hare must proceed through a racecourse. Along the way, both the tortoise and the hare run into obstacles (the squares seen in the path). When the hare runs into these obstacles it stops and waits a while, but the tortoise keeps on going. You can change the speed of the tortoise or the hare, and can alter how long the hare waits when it runs into an obstacle (by changing a parameter called "laziness"). The magnified sample (Fig. 1b) shows that the tortoise (far right) does in fact beat the hare (far left) to the finish line (the vertical line on the right).

Aggregation

In this project, the environment starts out with one painted patch at the center of the screen. The turtles move randomly. If they walk next to a painted patch, then they paint the patch that they are on and get stuck there. This behavior results in the branching growth pattern (Fig. 1c). While the author of this model didn't know it when she started, this simple process models a well-studied phenomenon, called diffusion limited aggregation, which is a growth process seen in systems ranging from lightning to cities to ice crystals.

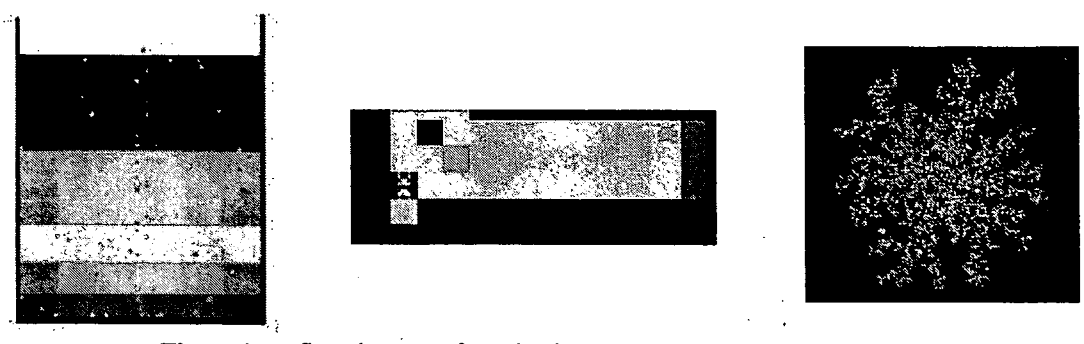

Figure 1a-c: Sample output from the three simulations (from left to right): convection (a), tortoise and hare (b), and aggregation (c).

Many of the Challenges were accompanied by "off-screen" activities that provided another way for participants to connect the abstract notions of dynamic complexity to their own personal experience. For instance, one morning, participants "flew" around the parking lot trying to form cohesive "bird flocks" without the assistance of a leader. Though we do not provide a detailed explanation of the activities here[4], many teachers reported that the combination of activities and Challenges enriched their ability to think with and about simulations.

In post-workshop surveys teachers described the importance of the off-screen activities. "They [off computer activities] were excellent. They helped frame the big picture." The combination of these activities and the computer modeling Challenges proved to be effective for the teachers. "Pairing off-line and on-line activities [was] very powerful. The games gave us *great* insight into rules and actions which could profitably be explored on the computer [emphasis in original]."

Results

By participating in activities and generating solutions to the Challenges, teachers changed their beliefs about the concepts that they teach and the ways in which they can teach them. In particular, these teachers expanded their knowledge of the nature and role of models in research and education. Many commented that designing and creating their own models greatly increased their appreciation of models' capability to reflect patterns and processes in the real world. They noted that the Challenge structure of the workshops helped them build this understanding incrementally, in a manner that they could adapt for use in their classrooms.

By building a diverse set of models teachers not only created new content for their classes, but also explored different ways to engage students in various aspects of their curriculum. Not surprisingly, teachers reported a higher level of comfort in building and using models at the close of the workshops than they did at the beginning. In addition, the workshops challenged many teachers to rethink their notion of how they and their students build new understandings.

Scientific Method

At its best, the nature of the modeling process supports experimentation and investigation. Unfortunately, many people—including most of the workshop participants—view scientific experimentation and investigation as a rigid set of procedures that must be followed in sequence in order to arrive at a scientifically valid result. During the workshops we created an environment that mirrored the complex, collaborative, and non-linear nature of investigation in the scientific community (Kraut, Egido, & Galegher, 1990; Latour, 1988). After the workshops, both science and non-science teachers alike reported a change in their conceptualization of the scientific method. "[The workshop] supported and encouraged directions away from the 'traditional' scientific method approach, which is almost like 'drill-and-kill' in some classrooms." After successfully solving a difficult modeling problem, one teacher commented that "[this experience] made it clear to me that we enter experiments with good intentions of following the 'scientific method', get some observations [that] lead us astray, and quickly abandon our intentions to follow a hunch." While this methodology could be superficial if used exclusively, some amount of open exploration is a critical addition to teachers' prior conceptions of the scientific method.

On the final day of the workshop, one teacher articulated the following qualities of good experimental design:

Base [it] on previous experience, observations, and play,
Gradually identify possible variables; perhaps gather more information,
Eventually establish hypotheses,
Design experiments, and
Analyze results: draw conclusions that generate *NEW* observations, hypotheses, designs [emphasis in original].

This expanded view does not reject the common notions of experimentation and investigation as much as it places those activities in the context of creative exploration toward a goal. While many people associate the scientific method with only biology, chemistry and physics classes, the reactions of these teachers suggest ways that this pattern of inquiry might be effectively applied in many disciplines.

Teacher and Student Learning

The model construction process served as a means of strengthening the participants' understanding of subject area content and pedagogical principles. While we did not attempt to directly teach participants information

[4] See (Colella, Klopfer, & Resnick, in press) for further information about activities.

about their own subjects, we were pleased that the model building process helped them to confront challenging issues in their curricula. For example, one group clarified their understanding of genetics by building, debugging, and presenting a model of inheritance. Another pair of teachers solidified their understanding of molecular motion. "The workshop has also changed my idea of what programming in teaching is for. It is at its best when it facilitates learning, especially when a concept is better understood. I am pleased with the understanding of molecular motion that Bob and I achieved by trying to get a working model."

As teachers grappled with content-related issues through the process of building their own models, they began to see the value of this process for their students' learning as well. Teachers expressed appreciation for the way that designing and creating models enabled them to push beyond the limits of their pre-existing knowledge. "The class has deepened my understanding of learning. There must be a constant interchange between the abstract and the real. In teaching, I must always lead the students to learn in an open-ended way that also undergoes this interchange." In addition to teaching workshop participants about building models, we also modeled a pedagogical form that is underutilized in high school classrooms. We are pleased that teachers were so enthusiastic about adapting this method for their own use.

Student Results

The benefits of teachers developing simulations, instead of using pre-built simulations, extend to their students, even when the students simply use the models that their teachers created. For example, a few teachers teamed up to produce a series of ecology models and associated curriculum. The teachers then used these materials in their own classes and passed the unit on to a few colleagues for use in their classrooms. Some interesting differences emerged between the two groups of students—those whose teachers had actively participated in the creation of the models and those whose teachers were using materials constructed by others.

Both groups of students were given identical written instructions. The instructions described how to use the simulations and included some sample questions to which students could refer as they explored the simulation. The students were then asked to design and conduct an experiment to elucidate an aspect of the simulation that interested them. Many more students (60% vs. 15%) in the classes of the teacher-developers successfully designed and conducted an experiment, meaning that they identified a topic to explore and then ran the simulation under various conditions to investigate different responses. The other students simply wrote short descriptions of some behavior that they noted in one iteration of the simulation (e.g., all of the birds died) or described scenarios in which they forced the simulation to behave in a particular way (e.g., I couldn't get all of the birds to die).

Another disparity between the students of the developers and those of the other teachers concerned the complexity of the observations that the students made. The observations of the students in the classes of non-developers tended to be one-dimensional, tracking only one species in the simulation at a single moment in time (e.g., the wolves died). Multi-dimensional observations (present in 23% of non-developer's students and 56% of developer's students) addressed the interactions of multiple species and/or the dynamics of a species over time (e.g., a high wolf population seems to drive the sheep population down).

Both sophisticated experimental design and multi-dimensional observations reflect the potential for deep learning on the part of the students. The preliminary stages of our assessment of the effects of teacher model building suggest that such activity may contribute to increased student achievement. We are continuing to track the progress of the teachers and their students. In the future, we will use these results as a way to assess the long-term effectiveness of this teacher professional development program.

Future Directions

During the workshops, teachers have successfully collaborated on interdisciplinary projects. Model building is an inherently interdisciplinary process, and the workshops support and encourage cross-disciplinary teams. Yet, the structure and culture of many high schools make this same collaboration difficult. We are continuing to identify and develop techniques that will enable teachers to recreate the successes that they enjoy at the workshops in their own school environments.

Through the StarLogo workshops, we have attempted to broaden the notion of hands-on learning by providing a concrete, replicable example of learning through designing and creating. The process of exploration and investigation in which teachers engaged during the workshops can be extended to many areas of the curriculum. Teachers who have participated in the workshops note that it is sometimes difficult to integrate these activities with the rest of their curriculum. We believe that the best measure of the success of professional development activities is their classroom efficacy. Though we continue to modify the workshops to address these issues, we are also creating ways to support teachers in their use of these activities throughout the year.

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Acknowledgements

We would like to thank the all of the workshop attendees for their enthusiastic participation and the Santa Fe Institute for their ongoing support. Also, we would like to extend special thanks to Mitchel Resnick (MIT Media Lab), Ginger Richardson (Santa Fe Institute), Larry Latour (University of Maine), and Nigel Snoad (Santa Fe Institute), without whom the Workshops would not have been possible.

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