Teaching Complex Dynamic Systems to Young Students with StarLogo

ERIC KLOPFER, SUSAN YOON, AND TRICIA UM
Massachusetts Institute of Technology
USA
klopf@mit.edu
syoon@mit.edu
triciau@alum.mit.edu

In this paper, we report on a program of study called Adventures in Modeling that challenges the traditional scientific method approach in science classrooms using StarLogo modeling software. Drawing upon previous successful efforts with older students, and the related work of other projects working with younger students, we explore: (a) What can younger students learn about complex systems and scientific methodology using this set of educational technology tools; (b) How do they respond to the open-ended nature of the Adventures in Modeling curriculum; and (c) How can the curriculum be adapted to better meet their needs. Using a naturalistic paradigm, we investigate differences between fifth and seventh graders and how, as a group, they respond in a different manner than other older students with whom we have worked. We also evaluate the degree to which their projects and practices embody the modeling and complex systems understanding that we have seen these activities promote in older students. We found that while students initially struggled with several aspects of the complex systems paradigm and required additional scaffolding, most of the students successfully built projects that demonstrated at least a rudimentary understanding of systems and how to analyze them. In comparison, the fifth graders were more readily engaged by the Adventures in Modeling curriculum, perhaps due to the playful design and exploration that StarLogo modeling encourages. This finding
echoes other researchers (Rieber, 1996) who have supported a similar notion that student learning at this level could benefit from greater play. This successful implementation of complex systems learning at a young age is important because, like many deep-rooted misconceptions in science, it may be easier to dispel the misconception of the centralized mindset (Resnick, 1994) at an earlier age before it has been reinforced by years of schooling.

INTRODUCTION

Emphasis in school science programs is often placed on following a prescribed “scientific method” in which students confirm or disconfirm pre-defined hypotheses in a linear, logical sequence. Such activities fail to incorporate and thereby acknowledge that (1) authentic scientific investigations require the allocation of a great deal of time to a kind of non-linear exploration, (2) variables are not provided and are often constructed, and (3) flaws in methodology and interpretation are constantly scrutinized; this may lead to the development of alternative explanations (Chinn & Malhotra, 2001). This false practice of the scientific method leaves students with a fundamental misunderstanding not only of the practice of science itself, but also of the nature and behavior of the systems scientific research attempts to understand. Furthermore, the linear nature of investigation and quest for the right answer fostered by traditional school science (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duschl, 1990) implies, amongst other things, that there is a one-to-one cause and effect relationship between variables, i.e., that any given input to a system will lead to a specific outcome. This type of analysis ignores important real-world complex system dynamics such as random effects and feedback that can produce unexpected results (Chinn & Malhotra, 2002). Research (cf. Resnick, 1996; Penner, 2001) has shown that students struggle with understanding such complex systems despite the importance of this conceptual domain in high school science (Jacobson, 2001). The role of complex systems in authentic scientific practice and the recognized place of modeling in the curriculum (American Association for the Advancement of Science, 1993) indicate that improving student understanding of complex systems and conveying more authentic scientific methodologies ought to be a significant component of science education reform.

In this paper, we report on a program of study called Adventures in Modeling that challenges the traditional scientific method approach in science classrooms while building understanding of complex systems. It was
created to help teachers and students investigate complex systems through designing, building, and analyzing models of physical and social phenomena using multiple variables interacting at any given time. This design-construction process is thought to be critical in enabling students to construct a deep understanding of scientific concepts (Papert, 1980; Kafai & Resnick, 1996). Using a well-developed and stable computer modeling tool called StarLogo, students program agents or creatures to interact with one another and their environment, and study the emergent patterns from these interactions (Resnick, 1994). In StarLogo, one writes simple rules for individual behaviors of agents that "live" and move in a two-dimensional environment. For instance, a student might create a model of an epidemic by defining rules for healthy and sick people that describe how they should move, how they interact, and how they become healthy or sick. Because StarLogo makes use of graphical output, when the student watches many people simultaneously following those rules, s/he can observe how patterns in the system, like the spread of a disease, arise out of individual behaviors.

BACKGROUND

Adventures in Modeling

StarLogo (http://education.mit.edu/starlogo) has been available for several years and has been adopted for classroom use in countries worldwide. However, for many teachers and students, it has a high barrier to entry due to programming model requirements (although it is accessible even to novices), and a relatively new domain of knowledge. To address this difficulty, an introductory guide to modeling complex dynamic systems was created (Klopfer & Colella, 1999; Klopfer & Colella, 2000). The Adventures in Modeling (Colella, Klopfer, & Resnick, 2001) curriculum (http://education.mit.edu/starlogo/adventures) was designed to introduce participants to the computational and cognitive aspects of modeling complex, dynamic systems. It was constructed to foster a playful, cooperative, and creative spirit while at the same time providing adequate structure for learning how to build models. To accomplish this balance between structure and exploration, activities are organized around a set of open-ended StarLogo design challenges on the computer and a series of off-computer activities in which participants enact and analyze a simulation.
Figure 1. StarLogo Model of a viral Epidemic. The left panel displays the code for the model that is running. The right panel shows the user interface (buttons and sliders) as well as the running model in action.

Each challenge is a problem statement that is meant to guide participants’ explorations and spark their creative thinking. For example, one challenge asks participants to build a model in which creatures react to their environment. In response to this challenge, one might create a model of a ball bouncing off a wall, a car following road signs, or a bee navigating to its hive. Every challenge includes sample projects, which students are encouraged to explore. The challenges and accompanying sample projects facilitate model design and construction, build familiarity with the StarLogo environment, and introduce the principles of complex systems.

Although “on-screen” computer modeling is one focus of our workshops, “off-screen” activities provide another way to connect abstract notions of scientific systems to personal experience (Colella, 2001a). These activities allow participants to think about concepts like exponential growth, local versus global information, and group decision-making from a personal perspective. For instance, in one activity, participants become members of a growing population as they follow simple birth/death rules that can easily be altered and understood. To provide an additional layer of collaborative communication, this curriculum has also been used in conjunction with the StarLogo design discussion area, an online forum for posting and discussing solutions to the design challenges, based on the design discussion area in Kolodner and Nagel (1999).
Previous Research and Current Goals

Past work has concentrated on using the Adventures in Modeling curriculum at the secondary and post-secondary level (Klopfer & Colella, 2000; Colella, 2001a). Students in these classes and workshops typically enter with many of the misconceptions about complex systems and scientific understanding that are characteristic of the traditional scientific method approach, many of which are echoed by other researchers (cf. Jacobson, 2001), including misconceptions about emergence, centralized control, sensitivity to initial conditions, and the predictability of systems. When designing, creating, and testing their models, these misconceptions are generally manifested in two ways:

(a) **While building models** - Rather than stochastic simulations that can exhibit a range of behaviors, learners tend to build illustrative models (or animations) that demonstrate a process in a deterministic way, such as multimedia animations that are becoming quite common in schools.

(b) **When experimenting with models** - Learners push a button, observe an outcome, and create an explanation, not taking into account random effects and initial conditions that might produce variable results for a given set of parameters.

These materials have since been used with hundreds of teachers, and thousands of students around the world. Previous case studies have found that the Adventures in Modeling curriculum can help dispel these misconceptions (Taylor, Noll, Colella, & Klopfer, 2001; Colella, 2001b). Currently ongoing research involving large scale implementation (Yoon, Klopfer, Richardson, & Taylor, 2004) provides further evidence that these materials can be effectively used to help build understanding of complex systems analysis in secondary school students. These materials were originally designed with secondary school students as an audience. However, numerous educational technology researchers have suggested that young learners can also be introduced to concepts of programming and modeling. Logo (Papert, 1980) has a long tradition of use beginning in early elementary school. KidSim/Cocoa/Stagecast Creator (Cypher & Smith, 1995) brought modeling and simulation to children through a simple graphical programming interface. Boxer (diSessa, Abelson, & Ploger, 1991) has also made inroads into the earlier grades by modeling physics and mathematical reasoning, while
building understanding of functions and variables. Other researchers have reported success in introducing programming (Kafai, Ching, & Marshall, 1998), and other forms of modeling (Lehrer & Schauble, 2000) to young students. StarLogo’s programming environment, combined with an emphasis on multi-agent systems, provides a unique opportunity for learning about complex systems, but also presents potential challenges for working with younger students. Given the success of the other modeling environments, the question that we explore is not whether the students can learn to program at a young age, but specifically: (a) What do they learn about complex systems and scientific methodologies with this set of educational technology tools; (b) How do they respond to the open-ended nature of the Adventures in Modeling curriculum; and (c) How can the curriculum be adapted to better meet their needs. In this paper, we investigate differences between fifth and seventh graders and how, as a group, they respond differently than other older students with whom we have worked. We also evaluate the degree to which their projects and practices embody the modeling and scientific principles that we have seen these activities promote in older students.

METHODOLOGY, PARTICIPANTS, AND DATA SOURCES

The study was conducted in a local K-8 public school in Cambridge, Massachusetts, selected because of its proximity and diverse student body. This school was a fairly typical urban school with about 500 students (weighted towards the earlier grades). The student body consisted of roughly 60% minority students, with 35% on free and reduced lunch programs. Working with the principal, we identified the fifth (ages 10-11) and seventh (ages 12-13) grades as the target for the project. Each grade had approximately 40 students, although as typical of urban schools those numbers fluctuated slightly over the course of the project. We met with the two fifth grade teachers, the seventh grade math teacher, the seventh grade science teacher, and the technology teacher to create a schedule. The original plan was to meet with each class twice weekly for an hour and a half (two blocks). The classes were taught in a computer laboratory with 25 iMacs. The instructional team consisted of one faculty member and five undergraduate teaching assistants who rotated the teaching duties such that there were two instructors in the computer laboratory at most times. The regular classroom teacher was also present at all times. However, since these teachers were learning at the same time as the students, they served mostly to answer simple questions. The total duration of the project was seven weeks
during which the intention was to cover challenges 1-5 from the Adventures in Modeling curriculum, in addition to a final student-selected project. The classes were designed such that students created one StarLogo project each week in response to a challenge and spent additional time engaging in the off-computer group activities.

In consultation with the teachers, a decision was made to focus on the scientific method of investigating models of complex systems and make connections with the Massachusetts Frameworks for Technology, which teachers have had trouble meeting. One last minute change was the reduction in time for the seventh graders to two weekly meetings of 45 minutes (instead of 90 minutes). This change highlights the difficulties of long-term implementation in real schools (Cuban, 1986).

Several data sources were collected for analysis of study goals. These included:

Student Projects

All of the students’ projects were posted to the StarLogo design discussion area (DDA), where they could later be analyzed by the research team. Students were told that the StarLogo DDA was a public forum. In addition to the models themselves, the StarLogo DDA required students to answer several short questions about why they created their model, what it did, and any special features it had. All of the data from the DDA was tagged with unique student identifiers to be later correlated by grade. Each project from every student was reviewed by the researchers and categorized based on the code and the design. Since the projects were relatively short (typically 10-20 lines of code) and based on a common set of instructions, categories of behaviors could be quickly synthesized from the collection of projects.

Lab Notebooks

Students were required to make daily entries into a paperback lab notebook. On most days, the students were simply required to make several notes on what they had done in class that day, and what they might try for the next class. As the students moved into their final projects, they were also required to write down data from the experiments that they conducted. Lab notebooks were collected once in the middle of the project for review, and then again at the end of the project for analysis.

Video Footage

All of the off-computer activities and associated discussions were videotaped. Final presentations, where students spoke about their project for 2-3 minutes on the last day of class, were also taped.
Online Surveys

Online surveys were taken by the students on the first and last day of the class. The surveys asked the students several questions about their beliefs and understanding of models and simulations. There were 10 questions where students used a Likert scale (1-5) to express their agreement (5 is maximum) with statements about scientific models (i.e., scientific models: “help make predictions,” “show how something works,” “are three-dimensional,” “have movement,” “are accurate,” “all use computers,” “always represent the truth,” “give the same answer every time,” “can be interactive,” “can be used to conduct experiments.” There were an additional 10 items that asked students to identify which items could be thought of as models (including “Monopoly,” “a diorama of a desert,” “a poster of the solar system,” “a matchbox car,” “a puppet,” “Sim City,” “a weather map,” “Flight Simulator,” “Doom,” and “a road”). These represent items that an expert panel of professional modelers deemed to be models or not models. These questions had been piloted in previous StarLogo studies with both students and teachers, and are designed to provide some background information on how broadly or narrowly students define models. Several additional questions were given on the exit survey assessing student attitudes about models, including their judgment of the difficulty of creating certain types of StarLogo models, and what kinds of StarLogo projects they would work on if the project were to continue.

Task-based Interviews

Two interview sessions were conducted with a subset of students from the project. In each of the interviews, students were presented with a StarLogo-based task, which they were asked to complete while they thought aloud about what they were doing. These videotaped interviews, conducted by one of the trained undergraduate researchers, lasted up to 15 minutes (if the student needed it) and ranged from 10-15 minutes. The researcher primarily presented the problem, and prompted the students with a short list of pre-defined responses (e.g., “Have you figured out what all of the buttons do?”) if the student said he/she was stuck. The StarLogo tasks chosen were “Mystery Models” from an activity that has been conducted many times with secondary school students and teachers. Each mystery model is a StarLogo model with unlabeled buttons and sliders. Users are given the task of figuring out what the buttons and sliders do by simply manipulating them and observing results. The specific models (one that creates different shapes and another on contagion) are described in further detail below. Because of
the reduced time in the seventh grade classes, we did not conduct interviews with the seventh graders. The tasks require some basic StarLogo knowledge. Therefore, they were presented with one in the middle of the project and one at the end. Time restrictions limited the sample size to 12 students. The videotaped responses were analyzed and validated independently by a pair of researchers for themes across students as described below.

While the general categories of interest were defined by the research questions, the specific sub-themes emerged from the experiences and perspectives of the students in the project. In order to promote the emergence of these themes, a naturalistic paradigm was chosen as the research design for this project. This paradigm enables conclusions to emerge from the particular situations under study (Lincoln & Guba, 2000). The multiple data sources listed above were analyzed and triangulated to discover and develop the themes as borne out by the students in the project.

RESULTS AND DISCUSSION

A. What do younger students learn with this set of educational technology tools?

1. Generative Hypothesis Testing

![Figure 2. The Mystery Shapes Project](image-url)
The first project used in the interviews, entitled Mystery Shapes (Figure 2), contained six buttons and three sliders (sliders change the values of variables). More than half (7/12) of the students consistently had difficulty discovering the purpose of buttons that did not have immediately observable effects, or that had effects that were dependent on the initial conditions.

For example, button 3 makes the turtles take one step forward. If this button is pressed at the start of the project (without any turtles), it will not do anything. If this button is pressed from the default setup of a stack of turtles in the center of the screen (facing different directions) it will make a ring. But, the instruction itself is just “move forward.” For example:

Student (fifth grade male): …button 3 [clicks on button while no turtles are on the screen] doesn’t do anything [clicks the button several more times] hope it doesn’t do anything.

Or

Student (fifth grade female): Let’s see, button 3 [clicks on button] makes a ring. [moves on to next button]

Some time later, the student comes back to button 3.

Student: [clicks on button] oh, it makes a bigger circle if you already have a circle on the screen.

Another button (button 4) creates a new stack of turtles at the center of the screen. The turtles are of different colors, and only the top one shows up. When investigating the project, one student stated:

Student (fifth grade male): Button 4 [keeps clicking on button] doesn’t do anything [the slider next to it was set at zero]

Later the student revisits the button.

Student: [clicks on the button a few time successively now that the slider has changed] Whoa. This one changes the colors of the turtles [clicks again several more times] it changes the color.

These mistakes typify student behavior in which they were quick to jump to conclusions about the behavior of a button based on a single instance of its use, without varying the initial conditions, or verifying with subsequent actions.
Figure 3. The Mystery Epidemic Project

The second project, internally called “Mystery Epidemic,” was modeled using sick (red) and healthy (green) agents. Healthy agents became sick by contacting sick ones and could recover with a certain probability. There were three buttons and sliders (and one monitor that displayed data). Results showed that all of the interviewed students eventually correctly identified the project as having to do with disease, germs, or sickness. During the initial moments of exploration, many of the students still fell into strategies that caused them to identify premature conclusions after a single iteration or observation.

*Student (fifth grade female):* [changes a slider that increased infection rate and sees more red turtles] this slider makes more red turtles.

Several students initially remarked that the red agents were eating the green ones as red seemed to increase and green seemed to decrease. Little consideration was given to the function of recovery rate (a pivotal concept necessary for understanding overall dynamics), and few students considered that total numbers always remained constant, which would be a good indication of what was happening or not happening in the project.
Student (fifth grade girl): [after playing with the project for a couple of minutes] The red ones and green ones are both living, but the red ones are like the predators. They are the hunters and they eat the prey [numbers of the “prey” are decreasing because they are becoming infected and changing from healthy to infected, but the numbers are constant].

However, after working with the simulation for some time, some of the students changed their minds as they observed the conservation of the total number of agents, which provided evidence of alternative and generative hypothesis testing.

One student was initially convinced that the model was of termites piling wood (a model that had been seen earlier in the course).

Student (female fifth grade): This is termites. [Slider] number 3 changes how fast the termites go. I know it changes how much they eat, how fast they separate the wood. But, right now they’re not putting the wood into piles. See how much faster and how much more green when slider 3 is up.

When things did not fit into her hypothesis, she modified it slightly.

Student: Green can’t be wood because wood can’t move.
Green is turtles. Turtles eat the termites, or they just kill them. [Slider] number 3 changes the speed of the turtles.

As she collected more data, she further modified her hypothesis.

Student: Now it looks like termites eat turtles. [Slider] number 3, when it is low termites eat turtles.

Finally, after some more tinkering, she saw that the data did not fit her hypothesis and she was willing to abandon the initial hypothesis in favor of another.

Student: Maybe it is germs. Germs yes. The green could be medicine and it is fighting away red germs. [Slider] number 3 makes the person take more medicine.
2. Random Variation and Systems Understanding

Despite the slow start, students eventually demonstrated understanding of the ideas of modeling and complex systems. One trait of complex systems (Chi, in press) that is not a part of the traditional science curriculum is the notion of random events. When modeling and analyzing systems, randomness is an important and powerful element. There was some evidence in our study that students were able to grasp this concept to a greater or lesser extent. For example, all of the students’ final projects showed some understanding of random variation in models. While no projects explicitly encompassed variation in initial conditions, most allowed the user to manipulate variables so that results could change over time. In their traffic simulations, cars could be added to increase the volume of agents, which would alter the system dynamics. In analyzing the students’ lab notebooks, many students ran replicates of experiments and recorded them as charts or graphs. Several students turned the road into a racetrack and then recorded which color won the race (Figure 4).

![Figure 4. Sample Fifth Grade Traffic Projects.](image)

Further evidence came during informal classroom interactions. During the construction of final projects, two (male) fifth graders exclaimed to one of the instructors, “We had a breakthrough. Now we have the turtles wait a random amount on the orange squares and when they race, it makes sense. The same turtle doesn’t win every time.”

Likewise, in discussions that surrounded the off-computer activities, students identified the rates at which people moved, and the density of traffic as important factors in the determination of traffic jams. One (fifth grade female) student remarked, “When we had more cars we got more traffic… when there were enough of us going around in the circle, there was always traffic somewhere.”
3. Understanding of the Concept of Model

As a part of the entry and exit surveys, all students were asked to identify whether a series of items could be considered as “models.” In the exit surveys, several of the items showed marked increases in their ability to accurately identify models. These included, Monopoly (54% pre vs. 66% post), Matchbox car (58% pre vs. 89% post), SimCity (66% pre vs. 89% post), Flight Simulator (72% pre vs. 84% post), and Diorama of a Desert (1% pre vs. 94% post). This indicates that the students’ definitions of what a model could be were broadened through the course of the study. The students seemed to learn that a model could be many different things.

Two additional encouraging results on the exit survey were that 84% of the students believed “Anyone can create scientific models” and only 13% thought that “Scientific models give the same answer every time.”

B. How do younger students respond to the open-ended nature of the Adventures in Modeling curriculum?

1. Common Difficulties and Capabilities

Both fifth and seventh graders had difficulty in working with the open-ended nature of the design challenges. Analysis of classroom performance and submitted projects showed that students proceeded well during the initial stages in which they were exploring projects and learning the fundamentals of StarLogo. However, students experienced great difficulties applying their understanding when they were asked to create their own projects in response to the more open-ended challenges such as “design a project in which the creatures interact with their environment.” The students did not know where to begin with this idea. Even the sample projects with which they were provided were insufficient to prompt students to build their own projects. In order to better scaffold the learning process, further structure was provided in the form of starter projects. Although this intervention limited students’ ability to select and apply their own ideas, it enabled them to overcome what we term the “blank-screen” problem of initial design and construction. Instead of a totally open-ended final project, all of the students constructed models of roads and traffic jams. This restriction was welcomed by most of the students who still added things like potholes, changing lanes, and racing to the basic structure of their models.

Another notable challenge was evident in the pacing of the delivery of curriculum challenges. Whereas older students are expected to complete at
least five of the Adventures In Modeling challenges in the amount of time allotted to the study, pacing of the delivery of the material had to be decreased with the younger students although the amount by which the pace slowed varied by grade. Consequently, the students did not get as far into the curriculum as was originally planned for the 7-week period. Instead of completing the curriculum to Challenge 5, most classes stopped at Challenge 3.

2. Fifth and Seventh Grade Differences

Despite the fact that the fifth graders spent twice as much time per week on StarLogo, in the end both groups completed the same number of challenges and projects. In analyzing the final projects posted on the StarLogo DDA, there were substantial differences between the grade levels. Seventh graders used code that was more intricate than the fifth graders. Many seventh graders created traffic light procedures that regulated the flow of cars, in addition to the procedures that the cars themselves were following. However, beyond that the seventh graders nearly uniformly produced what could best be described as “uninspired” projects. All of their roads were geometrically shaped with no decoration and the behavior of the cars was minimally changed from the starter project (Figure 5).

Figure 5. A typical fifth grade (in this case female) traffic project (left) showing aesthetic improvements and personalization including the trees, flowers, and ducks, as well as a passing zone in the lower right corner. And a typical seventh (also female in this case) grade (right) project showing no personalization or improvements.
In contrast to the seventh graders, the fifth graders added extensive "computationally inactive" but aesthetic improvements to their projects and used a variety of road shapes. In addition, many of them added unique computationally active behaviors such as racing, passing, and crashing. Many of the enhancements that individual fifth graders created were passed along to their classmates. For example, the ducks seen in Figure 4 were found in several other projects from this class.

The exit surveys also identified a few notable differences in the perception of StarLogo modeling between the fifth and seventh graders. One section asked the students to rank the difficulty of creating particular models in StarLogo (e.g., the spread of a forest fire, a chemical reaction). The seventh graders consistently ranked the projects as being more difficult to create (on average 1/2 point on a five point scale) than the fifth graders. In a related question, students were asked what they would model if the StarLogo project were to continue for a few more weeks. The seventh graders picked very complicated systems (e.g., tsunamis, volcanoes) or systems that were not particularly appropriate to StarLogo (e.g., rappers [musicians], robots). The fifth graders chose projects that had already been referenced in the course (e.g., termites, predator and prey, a virus), or some relatively simple systems (e.g., a school, the game of tag).

C. How can the curriculum be adapted to better meet the needs of younger students?

In past work (Taylor et al., 2001) and in current studies (Yoon et al., 2004), it has been found that high school students (as young as ninth grade) readily embrace the StarLogo design challenges. Students may struggle with syntax or the selection of project topics during the program. However, many ultimately produce highly original and creative work. In one class, projects included a forest fire, a neuron, a highway, insect foraging, and tree growth. Depending on the range of student abilities, they have occasionally been permitted to proceed more rapidly than planned. Furthermore, after completing about half of the challenges, older students will often initiate a final project in addition to researching additional topics as needed.

In order to ascertain solutions to the last study goal, we were interested in understanding why the younger students, in contrast to the older past participants, faltered when presented with the open-ended design challenges. One piece of evidence of the source of this problem was found in the video footage of one of the introductory classroom discussions. In one class, several students raised their hands to ask the question, "What is a project?"
This response is particularly revealing about the level of implementation of project-based experiences for these students. Younger students may be challenged by extremely open-ended pursuits without adequate scaffolding (Vygotsky, 1978). This problem becomes more daunting when students have not had the opportunity to build up their own skills for working and playing in highly unstructured ways.

In addition, the slower pace with these groups was primarily due to students struggling with the specificity of the commands that needed to be issued to the virtual agents. Students struggled with the fact that agents could not speak English. The following excerpt of a (male) student-instructor interaction in a grade 5 class illustrates this point.

*Student:* I want my turtle to follow the path [yellow line drawn on screen]. And it doesn’t.

*Instructor:* How does it know how to follow the path?

*Student:* I told it to follow path [follow path written in procedures but not defined]

*Instructor:* The turtles only know how to do what you tell them to do, and you haven’t told it what follow path means. Do you think you can give it more specific instructions?

*Student:* I don’t know.

As shown by their behavior in class and analysis of the projects stored in the DDA, the most apparent difference between the fifth and seventh graders in this project was the relative willingness of the fifth graders to embrace StarLogo and the abstract open-ended nature of the Adventures in Modeling challenges. The Adventures in Modeling approach parallels the process of play (Rieber, 1996, Rea, Millican, & Watson, 2000). Once adequate scaffolding was created for the design of the students’ projects (Scar-damalia & Bereiter, 1991), they were able to think abstractly and run with the idea. They played with their models by changing their physical design, adding new behaviors or, as seen in the DDA, inventing stories about them. The following is an excerpt of a fifth grade boy’s story:

Once upon a time there was three ugly turtles who wanted to cross a street. They were so dumb that they needed directions. They could not read so they used colors to tell them where to turn. That’s [sic] how they created bumper turtles (the name of this particular project) on star logo [sic].
The fifth graders were willing to play in this environment, and explore the simple but powerful models that they created. Most were satisfied with what they had created and were eager to delve into more models of the same nature. In contrast, the seventh graders produced projects that satisfied minimal requirements, and were interested in continuing only if they could create projects on a grander scale. It is possible that the computational complexity threshold for stimulating interest in the seventh graders was much higher because they had been exposed to richer computer environments through video games and to more sophisticated software.

Alternatively, the source of this difference might lie in more developmental issues. The act of creating simple models infused with personal interests fits well with the playful construction and exploration typified by elementary school (Rea et al., 2000). The seventh graders had a regimented subject-based curriculum that was more focused on content and less on playful exploration. This was readily seen in several of the off-computer activities where students were required to enact systems. The fifth graders ran around and tagged each other, exchanged information, and became part of the enacted systems. The seventh graders clustered in groups of friends along the border of the play space (in the adjacent library) and only moved when forced by their teacher. This decrease in the "playful" culture as students move toward secondary school (Karaliotas, 1999) may have inhibited their ability to fully engage in the StarLogo design process. It is conjectured that high school students succeed not because they are playful, like the fifth grade students, but because they have developed a sufficient level of content area expertise to build models that are personally interesting to them. There is a good match between the areas of interest, the depth of understanding of content, and the tools available to high school students. The seventh graders fall between these two grades—without the strong "play ethic" of the fifth graders, or the deeper content area mastery of the high school students. It is unclear whether this difference is intrinsic to the age groups being discussed, or is constructed by an educational culture that encourages playful behavior in younger students and discourages it in older students. Simply looking at the science fair posters, all based on the same templates (i.e., all with the same hypothesis, methods, results, and discussion sections), around the school that showcase the latest seventh grade science work and comparing these to the Lego robotics used in the science sessions with fifth graders, it is evident that these differences are perhaps institutionally reinforced.

The effect of creativity in the fifth grade students was also likely magnified by the diffusion of creative innovations (Rogers, 1995) around the classroom. The fifth graders mingled amongst many of their peers, looking
at their neighbors’ screens and walking around the room when one of the classmates made a breakthrough. Ideas, ranging from paintings of ducks, to the design of particular roads, to procedures that made cars “die” when they hit a pothole, spread rapidly throughout the classroom. The seventh graders were much less mobile, typically at most looking at their neighbors’ (who were also their friends) screens.

CONCLUSION

The results provide evidence to support the application of the Adventures in Modeling curriculum with students younger than high school and even middle school levels. By constructing and exploring models using StarLogo, their final projects and analysis show that students can gain an understanding of the importance of repetitive hypothesis revision and testing, develop insights into some key systems concepts such as random variation, and become better able to classify models as a result of their participation. These learning outcomes address both the need for school science programs to adopt a more authentic scientific approach to investigations, as well as the call for inclusion of complex systems concepts in school science curricula.

In this study, all students were able to build models using StarLogo and the Adventures in Modeling approach, although additional scaffolding and a slower pace were required for these grade levels. This finding is important for two reasons. First, it shows that many of the principles of complex systems are not too complicated to be integrated into the classroom, even at the elementary school level. Young students can start to develop an understanding of some of the principles of complex systems and the skills required to understand them. This in turn is important because, like many deep rooted misconceptions in science, it may be easier to dispel the misconception of the centralized mindset (Resnick, 1994) at an earlier age, before it has been reinforced by years of schooling.

Based on the study results, continued application of the Adventures in Modeling curriculum at either of these grade levels would likely be enhanced by a greater repertoire of scaffolding tools that would allow students to select from a variety of starting points. While the projects, used as scaffolding in this study, provide a reasonable starting point further study is required to identify the most appropriate level of specificity of these scaffolds, and how that might vary by grade.

It is also hypothesized that fifth graders were more readily engaged by the Adventures in Modeling curriculum due to the playful design and explo-
ration that StarLogo modeling encourages. This is supported by the design of their projects presented in the DDA, as well as the discussion in their classes, and their participation in the off-computer activities. In general, seventh graders are placed in a difficult position; they are not encouraged to have a “play ethic” in school, while at the same time they have yet to develop the deeper content mastery of high school students. This place in “limbo” may have influenced their overall investment in the study. Other researchers (Rieber, 1996) have supported a similar notion that student learning at this level could benefit from greater play. The next iteration of this project will draw upon the present study results and investigate how to integrate appropriate play activities for middle school students.

References


