Creating a Modeling Culture:
Supporting the Development of Scientific Practice Among Teachers

Vanessa Stevens Colella

Bachelor of Science, Biology
Massachusetts Institute of Technology, June 1990

Master of Arts
Columbia University, May 1996

Master of Science, Media Arts and Sciences
Massachusetts Institute of Technology, June 1998

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in Media Arts and Sciences at the Massachusetts Institute of Technology

June 2001

Signature of Author______________________________
Program in Media Arts and Sciences
April 25th, 2001

Certified by ______________________________
Mitchel Resnick
LEGO Papert Associate Professor
of Learning Research
Massachusetts Institute of Technology

Accepted by______________________________
Stephen A. Benton
Chair, Departmental Committee on Graduate Students
Program in Media Arts and Sciences
Massachusetts Institute of Technology

Creating a Modeling Culture:
Supporting the Development of Scientific Practice Among Teachers

Vanessa Stevens Colella

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
on April 25, 2001 in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Media Arts and Sciences
at the Massachusetts Institute of Technology

ABSTRACT
This thesis describes the processes of teacher learning and explores the associated changes that take place in classrooms. It describes the Adventures in Modeling Workshops, which we designed and created to introduce teachers to the process of conceptualizing, building, and analyzing their own models of complex, dynamic systems. The Workshops facilitate the growth of a modeling culture among teachers by giving them the tools and the ability to pose, investigate, and answer their own questions. This research examines the development, sustainability, and impact of that culture. It describes how participation in a modeling culture can contribute to a scientific way of thinking, for both teachers and their students, and can help teachers bring authentic science practice into high school classrooms.

Employing technological tools developed at the Media Lab, we crafted an introduction to scientific modeling for teachers. These tools, used in concert with a constructionist pedagogy of design and creation, enable teachers to become full-fledged practitioners of modeling. Our workshop structure supports teachers as they learn to act as scientists, creating and exploring models of phenomena in the world around them, evaluating and critiquing those models, refining and validating their own mental models, and improving their understandings.

This work serves as a proof of concept for a structure and methodology that increases teachers' individual capacities and helps them integrate aspects of their learning into their own classes. It examines the role that new media plays in supporting new ways of thinking and enabling explorations of new domains of knowledge. It also serves as a platform for examining the details of three components of educational change: 1) the development of technology-enabled materials and activities for teacher and student learning, 2) the construction of a scientific culture among teachers through learning about, gaining fluency with, and exploring modeling technologies, and 3) the paths toward implementation of new content and educational approaches in teachers' classrooms. The results of this project provide one benchmark for evaluating the potential that new ideas and technologies hold for facilitating lasting change in America's classrooms.

Thesis Advisor: Mitchel Resnick
LEGO Papert Associate Professor of Learning Research
Massachusetts Institute of Technology

This research was sponsored by the National Science Foundation (grant numbers 9358519-RED and CDA-9616444), the LEGO Company, British Telecom, and the Thing Things That Think, Digital Life, and News in the Future consortia at the Media Lab.

Creating a Modeling Culture:
Supporting the Development of Scientific Practice Among Teachers

Vanessa Stevens Colella

Doctoral Dissertation Committee

Thesis Advisor

Mitchel Resnick
LEGO Papert Associate Professor
of Learning Research
Massachusetts Institute of Technology

Thesis Reader

Brian Smith
LG Electronic Career Development Assistant Professor
of Media Arts and Sciences
Massachusetts Institute of Technology

Thesis Reader

Richard Elmore
Professor
Harvard Graduate School of Education
Harvard University

Acknowledgments

Many people helped me over the course of this project. In particular, I would like to thank:

Mitchel Resnick, for advising and supporting me, for creating StarLogo, and for leading a research group that inspires exploration, innovation, and hard fun.

Richard Elmore, for his encouragement, his help in contextualizing my work, his refreshing perspectives on educational change, and his willingness to contemplate the effects of new technologies.

Brian Smith, for his simultaneously effective and entertaining commentary.

Eric Klopfer, without whom this project would never have gone so far nor been nearly so much fun.

Rick Borovoy, for his friendship, insight, and unsurpassed creativity.

Molly Jones, for her commitment and her enthusiasm.

The members and friends of the Lifelong Kindergarten group at the MIT Media Laboratory, especially Andrew Begel, Amy Bruckman, Missy Corley, Monica Linden, Fred Martin, Bakhtiar Mikhak, Randal Pinkett, David Williamson Shaffer, Brian Silverman, Carolyn Stoeber, Bill Thies, Diane Willow, and Karen Wisniewski.

Linda Peterson, for cheerfully and tirelessly keeping me on track.

The Santa Fe Institute, especially Ginger Richardson, Ellen Goldberg, and Andi Sutherland.

The participants and leaders of the StarLogo Workshops in Santa Fe and Boston, especially the participants of the 2000 Adventures in Modeling Workshop at MIT, and James Taylor, Richard Noll, Larry Latour, Nigel Snoad, and Gil Munden.

Bill Barowy, Linda Booth-Sweeney, Mark Guzdial, Janet Kolodner, Tim Koschmann, Joe Krajcik, Frank Levy, Marcia Linn, Nancy Roberts, Elliot Soloway, John Sterman, and Sheldon White—for providing encouragement, advice, and assistance along the way.

British Telecommunications, especially Graham Cosier, Pat Hughes, and Steve Whitaker.

On a personal note, I would also like to thank Giovanni Colella for his love and support, John and Dale Stevens for their unwavering belief in what I could accomplish and for teaching me how, and Grant Stevens for showing me first that it could be done.

Contents

1. 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.

Throughout history, most people, like the pioneers mentioned above, have created models out of wood, paper, metal, and mathematical expressions. In more recent times, computers have provided a new medium for building, analyzing, and describing models. Computers have made it possible for people to model more dynamic and more complex systems, paving the way for new kinds of analysis and discovery. Scientists and other researchers draw on the power and flexibility of computers to help them better understand and explain the systems that they study and to expand the range of systems that they can explore. Using computers, economists build models of commodity pricing, biologists build models of protein folding, historians build models of ancient civilizations, ecologists build models of habitat fragmentation, and physicists build models of subatomic interactions.

Computers also make it easier for novices to build and explore their own models—and learn new scientific ideas in the process. The Adventures in Modeling Project introduces teachers to the process of designing, creating, and analyzing their own models of complex, dynamic systems. Our goal is to engage teachers in authentic science practice by giving them the tools and the ability to pose, investigate, and answer their own questions. This project explores the growth of a modeling culture among teachers and the spread of that culture to science classrooms.

Research Problem

Much rhetoric in science education focuses on the need to make science learning more like the practice of science. Calls for inquiry-based science, developing skills for systems thinking, and fostering collaborative learning in science classes are all components of this focus. Many reformers argue that science education should—like science practice—consist of activities such as framing problems, devising experiments, collecting data, and refining hypotheses (National Committee on Science Education Standards and Assessment, 1996; Project 2061, 1993).

At the same time, people are calling for a tighter integration between technology and the disciplines that children study (Linn & Hsi, 2000; Means, 1998; Means & Golan, 1998; Shaw, 1997). Rather than viewing computers as add-ons to the curriculum, researchers and educators increasingly push for computers to be used to help enrich students' learning experiences. This move toward technology-integration fits well with the desire to support learning through authentic science practice. Like scientists, students can use computers to support and enable sophisticated experimental design, execution, and analysis. For example, using new modeling tools, students can collaboratively frame and solve problems, engage in iterative investigation, and modify their models based on new understandings. Teaching students to use computers for investigating problems and designing solutions can improve their understanding of technological tools as well as their understanding of the process and content of science.

Framed in this way, it seems a foregone conclusion that a large percentage of science classrooms around the country would use technology to help students explore the world around them.[1] However, this framing leaves out several key characteristics of our educational system, each of which impedes changes in science education. These characteristics include teachers' lack of familiarity with technology (as well as science practice), teachers' reluctance to adopt new methods and tools, and a general move towards standards and accountability that has stymied certain kinds of change (Cuban, 1986; Cuban, 1993; Tyack & Cuban, 1995). At the same time, increasing teacher shortages and the inability to recruit and retain talented, trained individuals for classroom jobs are becoming a top-level national concern. The large expected turnover in the teaching population in the coming decade provides an opportunity to reshape teacher preparation and professional development to support new kinds of technology-infused science education.

Many educational researchers aim to design materials and technological resources that change the nature of teaching and learning, and find their way into classrooms in a sustainable, scalable manner (Fulton et al., 1996; Kolodner & Guzdial, 1996; Koschmann, 1993; Newman, 1995; Papert, 1993). Unfortunately, the number of success stories is small. This thesis describes the processes of technological curricular development, teacher learning, and associated classroom change. It is meant to serve as a proof of concept for helping teachers increase their individual capacities and integrate aspects of their learning into their own classes. It is also meant as a platform for examining the details of three components of educational change: 1) the development of technology-enabled activities and materials for teacher and student learning, 2) the construction of a scientific culture among teachers, and 3) the paths toward implementation of new content and educational approaches in teachers' classrooms. Thus this thesis serves as both a specific instance of and general framework for thinking about teacher learning and classroom change.

Modeling

Kindergarten children use Cuisenaire rods and building blocks to investigate concepts of color, shape, and number. Third graders grow bean plants to explore the life cycle of plants and the various ways that living creatures respond to their environment. In elementary science, the questions that students want to investigate are aligned well with the available materials and the kinds of modifications that students can make to experiments (i.e., watering a bean plant with Coca-Cola or growing it in a dark room). Unfortunately, it has proven far more difficult to integrate authentic scientific investigations into the secondary curriculum. Many laboratory experiences at this level require a high level of technical proficiency, which in turn inhibits the exploration of students' "what if" questions. In secondary classes, laboratory materials and experiments frequently do not support or accommodate modifications that address relevant questions.

[1] Not all reformers would agree with these ideas. Conservative educators (e.g., Healy, 1998; Hirsch, 1987; Hirsch, 1996; Postman, 1996; Ravitch, 1983) typically call for a "back to basics" approach. There will always be divergent camps in education reform; this research offers one piece of a progressive solution to the challenges of providing high-quality K-12 education to all children.

Using computer modeling in secondary science classes facilitates students' exploration of complex concepts and enables them to engage in more authentic scientific investigations. Modeling environments are attractive for a number of reasons, including their ability to bring students into closer contact with phenomena that might not be readily accessible in the real world. For example, using a model of a Newtonian environment (Roschelle, 1996; White, 1993) students can simulate actions that would be difficult or impossible to observe in the world (like a world without gravity) and thus can see visual representations of theories in physics. Though modeling has become popular with educational researchers (Feurzeig & Roberts, 1999), like many other technologies, it has not yet penetrated most high school science classrooms (Cuban, 1986; Cuban, 1993; Elmore, 1993; Oppenheimer, July 1997; Tyack & Cuban, 1995). Our project encourages secondary science teachers to collaboratively engage in model building and exploration and bring aspects of that experience to bear in their own classroom teaching.

Research has shown that the process of creating models (as opposed to simply using models built by someone else) not only fosters model-building skills but also helps develop a greater understanding of the concepts embedded in the model (Confrey & Doerr, 1994; diSessa, 1986; Resnick, Bruckman, & Martin, 1996; Roschelle, 1996; Talsma, 2000; White, 1993). When people build their own models, they can decide what topic they want to study and how they want to study it. As their investigations proceed, they can determine which aspects of the system they want to focus on, and refine their models as their understandings of the system grows. Perhaps most importantly, building their own models helps people develop a sound understanding of both *how* a system works and *why* it works that way.

Using technological tools developed at the Media Lab—including Participatory Simulations (Colella, 2000), Thinking Tags (Borovoy, McDonald, Martin, & Resnick, 1996), and StarLogo (Resnick, 1994)—we have crafted an introduction to scientific modeling for teachers. These tools, used in concert with a pedagogy of design and creation, enable teachers to become full-fledged practitioners of modeling. They engage in the creation and development of scientific models and then go on to investigate and explore those same models. The use of these tools allows non-experts to act as scientists, creating and exploring models of phenomena in the world around them, evaluating and critiquing those models, refining and validating their own mental models, and improving their understandings.

Purpose of Study

This thesis examines the materials and learning environments that are required to build a modeling culture among secondary school teachers. It also explores the extent to which these new technologies, and their associated pedagogies, can become integrated in secondary school classes.

My main research questions are:

- How can we construct a modeling culture for teachers?
- To what extent are teachers willing and able to recreate aspects of that culture in their own classrooms?

Specifically, this thesis describes the computational and pedagogical materials that we created to support a modeling culture among teachers. Then, it explores the ways in which teachers learn about, gain fluency with, and investigate problems using modeling technologies. Finally, it describes how, when, and why teachers choose to integrate these modeling technologies in their classes. In the process, this research shows how participation in a modeling culture contributes to a scientific way of thinking, for both teachers and their students, and helps bring authentic science practice into high school classrooms.

By exploring these questions, I evaluate the potential that a new set of activities and materials holds for the professional development of teachers. I argue that creating a collaborative modeling culture among teachers enables non-scientists to frame, investigate, and better understand meaningful problems. And, I document under what conditions and in what ways teachers choose to integrate those activities and materials into their curricula.

While many researchers have created tools for secondary education, there are few projects that look at the process by which teachers learn about a variety of new tools and decide whether or not to implement those tools in their classrooms. A small number of research projects, e.g., LeTUS (Gomez et al., 2000) and WISE (Linn & Slotta, 2000), have begun to look at the potential of taking pre-built curricular units (with modifications from a subset of classroom teachers who collaborate with the researchers) and deploying them systemically. The Adventures in Modeling Project is unique because it attempts to influence the professional development and classroom activities of teachers through the use of a generalized tool—one for which teachers have an opportunity to create and customize their own content. Though the learning curve is steeper, we are encouraged by our initial success with teachers. We think that the flexibility afforded by our approach to modeling, and the way that this project focuses on teachers' intellectual and professional development, will result in both practical applicability and academic value.

The general shortage and large anticipated turnover in the teaching force demand that we document effective ways to prepare the next generation of science teachers. The results of this project provide one example that educational researchers, technology developers, and public policy makers can use to evaluate the potential that new ideas and tools hold for facilitating lasting change in America's classrooms.

Organization

This thesis is divided into seven additional chapters: Background, Designing the Workshop Structure, Cultivating a Modeling Culture, Combining Media, Building a Community, Transforming Practice, and Prospects for Change.

Background provides the contextual backdrop for the thesis. It discusses the nature of scientific practice, science learning—including teacher learning, and the challenges of changing teaching practice.

Designing the Workshop Structure describes StarLogo, the Adventures in Modeling text, and the pedagogy of our modeling Workshops. It also describes the data collection undertaken during and after the Workshops and gives a brief snapshot of the Workshop participants.

Cultivating a Modeling Culture proposes an operational definition of a modeling culture and explores teachers' entrance into that culture through their participation in the Workshops.

Combining Media explores an expanded notion of multi-media. It looks at the variety of media that we use to model complex, dynamic systems and how the use of non-computational models influences teacher learning and adoption of new ideas.

Building a Community investigates the role of a community of practice in the formation of a modeling culture. It describes the structures we used to create a context for scientific investigation, the ways in which teacher learning was influenced by the community interactions, and the tenuous nature of this community over time.

Transforming Practice details the barriers teachers perceive to altering their classroom practices. It also follows four teachers' paths to integrating new ideas and technologies into their teaching practices.

Prospects for Change concludes with a look at how the creation of a modeling culture can lead teachers, and their students, to engage in authentic scientific practice and postulates about the ramifications these findings have for future research and development.

2. Background

In developing and evaluating strategies for teacher learning and professional development we drew heavily on the practices associated with scientific research. This chapter describes several aspects of scientific practice, including the process of constructing new knowledge in science, the social context that supports that process, and the unique role that computer modeling plays in scientific research. After developing an understanding of how scientists create new knowledge, it turns to an exploration of how teachers learn new ideas about investigation and experimentation. It compares how that learning compares to the practice of science, with a special look at facilitating teacher learning through constructionism. Finally this chapter describes the historical failure of new technologies to engender sustained change in classrooms, in contrast to the oft-touted promise of technology as a reform agent.

Scientific Practice

One aim of the Adventures in Modeling Project is to engage teachers (and subsequently, dependent on teacher enactment, their students) in the process of authentic scientific investigation. However, we must first define what we mean by "authentic science." Some researchers have proposed that children should learn science by using *tools* that resemble those used by scientists (Edelson, 1997; Edelson, Gordin, & Pea, 1997; Edelson & O'Neill, 1994). The growth of the Internet has spurred others to focus on the importance of enabling science students to work with authentic *data* (Dimaraki, Black, & Brown, 1988), though some researchers have noted the challenges of this approach (Hancock, Kaput, & Goldsmith, 1992). In this project, we focus on involving teachers in the authentic *process* of science (Gardner et al., 1990; Hawkins & Pea, 1987; Latour, 1987).

To begin to understand science practice, it is useful to think of science from two different perspectives. First, what is the process of knowledge construction in science? How do scientists think, reason, and discover? How do they learn new ideas from one another? Second, what is the social or cultural context that frames and enables this process?

Science Process

"Science is a way of seeking order" about the natural world (Curtis & Barnes, 1989). Scientists go about seeking that order through a systematic process (diSessa, 1988) that aims to produce general, testable theories about our world. For the most part, the stuff of scientific investigations adds to our existing knowledge in the domain. Scientists work to identify facts and then use those facts to support and better articulate existing theory (Kuhn, 1962). This definition is significant because, while the practice of science depends on scientists possessing a great deal of knowledge about the domain in question, the content of actual scientific investigation is on the edge of what is known. As such, the practice of science is a generative one that results in new understanding.

The process by which scientists construct this new understanding is often misunderstood. Science is not an orderly or solitary pursuit. Scientists rarely follow a step-by-step process of gathering materials, hypothesizing about a subject, running an experiment, collecting data, and confirming or denying the initial hypothesis. Much exploration is required before a problem is well defined enough to be investigated in such a careful manner. In fact, by the time perfectly structured, replicable experiments are conducted (like in prescribed school laboratory exercises), most scientists are simply looking for the final confirmation that their ideas are plausible. Furthermore, the intellectual context in which scientists work has enormous influence on the kinds of questions they pose and the methods that they choose to pursue.

The day-to-day process of science that leads to the production of new content is rather tedious. Scientists work within an existing paradigm and attempt to fill it out in excruciating detail. Kuhn (1962) explains:

> Normal science consists in the actualization of [the] promise [of the paradigm], an actualization achieved by extending the facts that the paradigm displays as particularly revealing… Few people who are not actually practitioners of a mature science realize how much mop-up work of this sort a paradigm leaves to be done or quite how fascinating such work can prove in the execution (p.24).

Of course, not all of this actualization results in filling out the paradigm. Some of the most fruitful moments in scientific practice arise from the production of, and subsequent attempt to explain, inconsistent findings (Dunbar, 1995; Kuhn, 1962). Scientists make discoveries that mold or stretch the existing paradigm or create inventions that displace one paradigm with another. Yet, even these more exciting "ah-ha" moments derive from the described practice of science.

Latour (1987) provides a fascinating exposition of the ways in which the practice of science moves from laboratory benches and scientists' minds to become a part of the existing theory. The processes of experimentation and explanation are not sequential, as often seen in school science where labs are completed before "lab reports" are written, but intertwined. The act of articulating results serves to inform and modify experimentation at the same time that it aims to convince others of those results. Similarly, experiments themselves are a part of the explanatory procedure, helping to clarify issues not only for the audience but also for the scientists themselves.

Social Context

Scientists rarely make discoveries alone. As alluded to above, science is fundamentally a social enterprise. This is true not only because many scientists work on related problems and the problems on which they work continue to grow larger, necessitating cooperation. It is also true because of the nature of knowledge construction in the scientific domain. Interactions with colleagues, whether through personal contact, collaborative research, or reporting and evaluation of results, create an intensely social context for scientific practice (Dunbar, 1995; Kraut, Egido, & Galegher, 1990; Kuhn, 1962; Latour, 1987). Scientists practice as part of both a local research group and an extended scientific community.

In spite of this understanding, there is a prevalent vision of a scientist sitting at a desk, reflecting upon inconsistent findings, and revising his hypotheses accordingly. Latour observed that at some point those who hold this conception of discovery will be distressed to realize "how the few people who did everything nevertheless did so little" (Latour, 1987). Dunbar (1995) found that much of scientists' conceptual change occurs not when discovering those inconsistencies (which are often ignored or classified as errors) but when explaining them to colleagues. It was during these meetings that other scientists "tended to focus on the inconsistency, to dissect it, and either (1) suggest alternative hypotheses, or (2) force the [presenting] scientists to think of a new hypothesis" (Dunbar, 1995). The group interaction, not individual contemplation, resulted in the generation of scientific insight and conceptual change. In fact, scientists made use of this property of group interaction to mitigate against their own faulty individual reasoning. Latour (1987) explores the complementary role played by publications and rhetoric in transforming those ideas from local discoveries to discoveries that have currency in the larger scientific community. Thus, the process of conceptual change and the construction of new facts and tools involve local social interactions as well as community-wide interactions.

Dunbar (1995) offers the following heuristics for making scientific discoveries:

- Members of a research group should have different but overlapping backgrounds. This composition fosters group problem solving and analogical reasoning.
- Analogical reasoning should be employed when problems or inconsistencies arise.
- Surprising results should be noted and followed up on.
- Opportunities to interact and discuss research should be provided.

These heuristics serve not only to summarize our understanding of scientific practice, but also as a spring board to the kinds of activities in which aspiring scientists might engage.

Even with a clear picture of research practices, it is difficult to recreate these practices in the classroom. Most students view science as a bunch of useful knowledge of facts and formulas (Brown & Campione, 1990; Reif, 1990). Often, science labs do not even incorporate the very uncertainty that is such an integral part of the discovery process (Edelson, 1997). Typical school assignments focus exclusively on getting the right answer, instead of on the process of building a better understanding, leaving students (and many teachers) with the erroneous view that a wrong answer is an embarrassment to be hidden (Reif, 1990). Lunetta (1990) likens laboratory exercises more to religion than science, with their emphasis on ritual.

Modeling and Simulation

Much of scientific practice and process is independent of the particular domain in which it operates. Whether a scientist is studying genetic abnormalities in fruit flies or star formation in distant galaxies, the general practices and processes outlined above are equally applicable. Exploring, experimenting, and investigating with models introduces an added dimension to scientific research.

Modeling combines observational, experimental, and theoretical aspects of traditional science with synthesis and construction (Hut & Sussman, 1987). Modeling provides an opportunity for scientists to specify and test various factors at play in a system, understand interactions, and test assumptions. The process of building artifacts (in this case, models) enables them to observe the outcome of their ideas. Not only do those artifacts allow them to explore a system, they also provide a platform for questioning the assumptions that went into the model. Over the past couple of decades, the use of computer modeling, especially agent-based modeling,[2] has been on the rise in science (e.g., Axtell, 1997; Epstein & Axtell, 1996; Judson, 1994; Wilson, 1998).

---

[2] For an example of an agent-based modeling environment, see Chapter 3.

The same kinds of experiences that scientists have with modeling—creating artifacts, testing ideas, exploring interactions, and so on—are particularly effective strategies for helping new learners to reflect on the nature of their own understanding. The Adventures in Modeling Project engages teachers in authentic scientific experiences around content that is meaningful for them and their students. In our project, teachers create models, investigate dynamics, and discuss experimental results with their peers, much like scientists in a research laboratory.

Science Learning

Just as many non-scientists have naïve, and surprisingly persistent, notions of what it means to be a scientist, many people also have naïve conceptions of what it means to learn science. For those who are not professional scientists, these conceptions arise in a large part from their own experiences with school science. Though everyone has different experiences, many of them reinforce two of school science's premises: students should learn many facts about science and some of those facts should be illustrated through laboratory experiments. In this section, we will explore a different notion of science learning, based upon cognitive research.

Many science texts and labs are based upon the idea that "our scientific heritage has provided us with deep and counterintuitive understanding of the physical, biological, and social worlds and we want to teach at least some aspects of that understanding to youngsters" (Carey, 1986). Teaching these ideas is not, as was commonly thought prior to the latter half of the last century, simply a matter of telling them to children through lectures or text. That method is ineffective for many reasons, not the least of which is that children are not blank slates—they have their own preconceived ideas about the world. Early studies emphasized the need to confront students' incorrect or incomplete beliefs and simply replace them with the correct scientific understanding. Later work revealed that this process was ineffective and that students needed a way to connect new scientific knowledge to their 'preexisting schemata' or 'naïve knowledge structures' (Carey, 1986; diSessa, 1988; Hawkins & Pea, 1987; Reif, 1990; Schoenfeld, 1990).

In order to make personal connections between new understandings and existing ideas about science, students—like the scientists described earlier—needed to engage in constructing their own knowledge. DiSessa (diSessa, Hammer, Sherin, & Kolpakowski, 1991) and others (e.g., Duckworth, Easley, Hawkins, & Henriques, 1990; Hawkins, 1965; Papert, 1980) were proponents of the theory that scientific knowledge is not simply discovered and validated, it is actively constructed. Furthermore, it is not possible (or at the very least not the most effective method) to construct knowledge about topics in the abstract or topics to which you have no connection. Brown, Collins, and colleagues stressed the importance of reconnecting knowing and doing (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989). The work of learning science could not be done in the abstract. It needed to be contextualized in authentic situations. "The activity in which knowledge is developed and deployed is not separable from or ancillary to learning and cognition" (Brown et al., 1989).

This last move was the beginning of a trend in cognitive studies toward rethinking various aspects of what it meant to learn in an authentic context. Recently, this trend has expanded to look beyond the learner as an individual and think instead about the learner as one component in a larger system. The model of a "community of learners is based on the premise that learning occurs as people participate in shared endeavors with others, with all playing active but asymmetrical roles" (Rogoff, 1994). Like the scientific communities of practice (Lave, 1991) described above, communities of students can be the unit of learning, and knowledge can be constructed by the group as a whole rather than just by individuals in a group. For students as well as scientists, building new, well-integrated scientific understanding rarely comes from a single perspective (diSessa, 1988). Researchers continue to explore and refine the theory that scientific knowledge is socially constructed (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Dunbar, 1995; Kraut et al., 1990; Latour, 1987; Roschelle, 1996; Scardamalia & Bereiter, 1996; Vygotsky, 1978; Wertsch, 1998). An examination of the cognitive perspectives on science learning reveals a process that bears strong resemblance to the aspects of scientific practice that we explored earlier. A highly effective way for students to learn about science is by participating in communities of practice that actively construct scientific knowledge through inquiry into authentic situations.

Before exploring how the Adventures in Modeling Project supports such learning, it should be noted that, though researchers may be comfortable with the theory that scientific knowledge is socially constructed, this view stands in marked contrast to the views held by most teachers, parents, and students. Cognitive science notwithstanding, we must keep in mind that teachers, parents, and students all want to engage in (what they view as) "real school" and real science". While Roschelle claims that "learning to be a scientist is as much a matter of (1) forms of participation in social activity and (2) negotiation of shared meanings, as it is of (3) internalizing scientific representations and operations" (Roschelle, 1996), the standards committee defines scientific knowledge quite differently. According to the standards, science subject matter is "*knowledge specifically associated with* the physical, life, and earth sciences" and being scientifically literate entails "*understanding the nature of* science, the scientific enterprise, and the role of science in society and personal life" (National Committee on Science Education Standards and Assessment, 1996, p.21). Though this definition encompasses both the facts associated with science and the process associated with scientific practice, many teachers, parents, administrators, and even scientists focus more on the facts, or the 'knowledge specifically associated with' science, than the process, or the 'role of science in' building deep, socially and personally connected understandings (Keller, 1983).

Teacher Learning—Constructionism and Collaboration

Papert held that learning involves constructing knowledge and that a particularly good way to construct knowledge is through the creation of artifacts (Papert, 1980). We examine that view and the previously mentioned insights about science learning in the context of adult learning. Through the Adventures in Modeling Project, we aim to show that teachers can effectively learn scientific content and practice through the design and creation of artifacts—in this case models. Like other constructionist projects, we rely on collaboration to enhance and support the learning process (Koschmann, 1996b).

In order to develop deep understandings of scientific concepts, teachers and students—like the scientists described earlier—need to engage in the process of constructing their own knowledge (e.g., diSessa et al., 1991; Duckworth et al., 1990; Hawkins, 1965; Kafai & Resnick, 1996; Papert, 1980). To provide this experience, we encourage teachers to collaboratively engage in model building and exploration, which enhances their own learning experience (Resnick, 1987).

We also incorporate features of the design studio teaching model (see Chapter 3) to provide teachers with a structure for receiving generative feedback during the design and building processes. In integrating these ideas, we aim to foster the kinds of creative thinking that are an important part of the scientific enterprise, while at the same time providing a time-tested structure for community-based learning and peer review (Colella, Klopfer, & Resnick, 1999; Kolodner & Nagel, 1999; Shaffer, 1998).

We believe that teachers ought to learn with new instructional tools in a manner similar to the way that their students will learn with those tools (Ball & Cohen, 1996). Therefore, we engage teachers in the collaborative design, construction, and evaluation of models, in a manner consistent with constructionist theories of teaching and learning (Koschmann, 1996b). The process of model creation provides teachers with a learning experience that parallels the learning experience that they can create for their students. It also reinforces teachers' knowledge about both content and pedagogy in a non-confrontational manner (Fullan, 1995).

We contend that teachers' experiences in the collaborative processes of scientific investigation not only help them to support these constructionist learning environments for their students but provide collateral benefits as well. Our focus on collaborative construction and community evaluation of models highlights our underlying belief in the theory of teaching (in both workshops and classrooms) as assisted practice (Tharp & Gallimore, 1991). This stance allows teachers' experiences to become concrete points of departure when they transition to analyzing their own experiences as learners and considering how to incorporate similar ideas in their own teaching. This final process engages teachers in developing strategies for introducing new tools and practices in their own classes.

Obstacles to Classroom Change

The grammar of schooling (Tyack & Cuban, 1995) describes the basic, and largely unchanging, nature of teaching and learning in schools. It encompasses many different facets of the school experience, from the way in which activity is organized in classrooms to the curricular decisions that are required based on state or national assessments of student learning. School structure and culture constrain the types of activities that students and teachers can successfully engage in during the school day (Sizer, 1984). On top of the most basic issues (like access to computers), successful integration of new technologies into existing teaching and learning practices can be thwarted by a number of aspects of the grammar of schooling.

Many research projects create new teaching materials and train teachers in their use, but do not examine the changes that teachers must make when integrating these materials into their classes. As teachers integrate new tools, especially technology, into secondary courses, the following realities present some of their biggest challenges:

- The prevalent vision of technology as a means to increase efficiency
- The premium placed on individual teacher and student achievement
- The reliance on lecture as a means of conveying knowledge
- The rigid division between disciplines
- The regimented nature of the school day

- The isolated nature of teaching
- The inflexibility of the secondary science assessments

Each of these aspects of schooling is a challenge that teachers must grapple with if they want to integrate new tools and ideas in their classrooms.

Though many teachers are excited about new technologies (Cohen, 1996), new activities and materials are not enough to enable them to alter their own practice in the face of the challenges posed by the grammar of schooling (Elmore, Peterson, & McCarthey, 1996). In fact, while certain aspects of the grammar are imposed upon teachers by institutional or policy structures (like class scheduling and age-segregated classes) other aspects result from the behavior of the teachers themselves. As Coppola (2000) notes, many teachers actively choose not to bring technological innovations into their classes because they view their existing practice as "working" and judge their teaching methods to be effective. They do not necessarily see the same problems or subscribe to the same rationale for change as researchers do. Effecting change in the core practice of teachers requires helping those teachers to develop the capacity to reflect on and re-evaluate their existing practices. Changing the externally imposed and internally (teacher) generated facets of the grammar are both non-trivial tasks.

In the Adventures in Modeling Project, we created a set of educative curricular materials to help mitigate the complications that arise when new innovations meet the grammar of schooling. Using those materials, we work to build individual teacher capacity and support reflective practice through Workshops that facilitate teachers' participation in scientific processes (Knapp, 1997). Teachers work first on their own understanding of the modeling materials and then "decide how to focus and frame the material for students" (Ball & Cohen, 1996). The flexibility and range of materials and teacher experiences provide a framework for sustaining incremental improvements in practice. In the next Chapter, we describe both the materials and structure of the Adventures in Modeling Workshops.

3. Designing the Workshop Structure

Our aim in the Adventures in Modeling Workshops is to foster a modeling culture. We are primarily concerned with facilitating participants' uses of new tools to think with (Papert, 1980). This chapter describes the components that we designed to enable the growth of a modeling culture over the course of our two-week Workshops. Later chapters flesh out the ways that participants reacted to and interacted with these components and specifically address how our Workshop design facilitated the development of a modeling culture.

When we designed the elements of the Workshops, we wanted to create a new framework for engaging teachers in learning about scientific ideas and investigative processes. We had a clear idea of the kinds of experiences we wanted to provide and have refined the Workshops over time to meet our goals. Before describing each component of the Workshops in detail, it may be useful to understand our concept of the learning environment that we were trying to create.

Our guiding philosophy when we designed the Workshops could be loosely described as a multi-layered commitment to helping teachers think about the world through the use of models. Modeling tools have transformed the practice of science by allowing researchers to explore and simulate systems. These activities help scientists to test their assumptions, investigate alternate explanations, and study problems at varying levels of abstraction. We wanted to create a learning environment that built up teachers' skills and philosophies around a variety of modeling tools. The following table summarizes our design goals for the Workshops and the design principles we enacted to achieve our goals.

Design Goal:	**Guiding Principle:**
We want participants to develop deep understandings of the nature and content of modeling.	We structured the Workshop to enable participants to learn *about* modeling and *through* modeling.
We want participants to learn to design and create their own models and develop the capability to express themselves with the computational tools.	We developed an open-ended structure that enables people to model topics of interest to them, while at the same time giving them a common direction to pursue.
We want the Workshops to appeal to a wide audience, including teachers who do not possess any prior experience with modeling or computer programming and teachers from a variety of disciplines.	We assumed no prior knowledge, only interest, when we constructed the Adventures curriculum.
We want teachers to be able connect modeling to their experiences in the world.	We designed Activities and Participatory Simulations to help people use their own experiences to build connections between models and actions or patterns in the world.

We want to support multiple learning styles and encourage the development of new perspectives.	We combined on- and off-computer activities to allow people to develop an understanding of modeling that is not wedded to a single tool or a single approach.
We want to create a community of learners, who help each other discover and develop new ideas.	We conceived and followed pedagogical structures (some adapted from the design studio tradition in architecture) that facilitate communication and reflection.

These goals and principles helped us create the Workshop components, which are fully described later in the chapter.

Creating Models in StarLogo

During the past ten years, simulation modeling, especially as it helps people to understand complex systems, has become a mainstream use of computational technology. The widespread popularity of "edutainment" software like SimCity (Maxis, 1989), Civilization (Microprose, 1996), and the Sims (Maxis, 2000) gives a clear indication of the extent to which simulation games have permeated popular culture. While it can be useful to experiment with pre-built models like SimCity, a deeper understanding comes through building and manipulating models whose underlying structure is accessible (Feurzeig & Roberts, 1999; Klopfer, 2000; Klopfer & Colella, 2000; Resnick et al., 1996). Just as a young child learns more by building a bridge out of blocks instead of merely playing with a pre-fabricated bridge, designing and creating models affords richer learning experiences than simply playing with pre-built models.

The learning process that occurs during the exploration and creation of models is critically important in domains that require an understanding of complex systems, from economics and mathematics to physics and biology. In addition, this learning process fosters the kinds of higher-order thinking and problem-solving skills that are called for in science, mathematics, and technology standards (National Council of Teachers of Mathematics, 1998; National Committee on Science Education Standards and Assessment, 1996; Project 2061, 1993). With StarLogo (Resnick, 1994), people can build their own models, not just explore pre-built models. There are many benefits to building models: the creators can decide what topic they want to investigate; they can control the underlying rules that govern their models; they can alter the behavior that their models generate; and they can make connections between their models' behaviors and the underlying mechanisms. In short, they can develop a deep understanding of the phenomenon they have chosen to explore. Our Workshops help participants learn about complex systems and develop the ability to create models in StarLogo, from the conceptualization of an idea through the final implementation, analysis, and presentation of a model.

Several common modeling programs, including Model-It (Soloway et al.,1997), Stella (Roberts, Anderson, Deal, Garet, & Shaffer, 1983), and MatLab (Mathworks, 1994), enable the design and creation of models. To model a system in one of these environments, the creator needs to

describe how aggregate quantities change in the system. StarLogo approaches model building from a different perspective. In StarLogo, one writes simple rules for individual behaviors.[3] For instance, a student might create rules for a bird, which describe how fast it should should
watches many birds simultaneously following those rules, she can observe how patterns in the system, like flocking, arise out of the individual behaviors. Building up models from the individual, or "bird," level enables people to develop a better understanding of the system, or "flock," level behaviors. StarLogo was designed to enable people to build their own models of complex, dynamic systems. Unlike many other modeling tools, StarLogo supports a tangible process of building, analyzing, and describing models that does not require advanced mathematical or programming skills. Using StarLogo, people can build and explore models—and in the process they can develop a deeper understanding of patterns and processes in the world around them.

StarLogo is a programmable modeling environment that enables the creation of models with many interacting agents. These agents, usually called creatures or "turtles",[4] live and move around on a two-dimensional environment. To create a model, you write rules that describe what the individual turtles do in their environment. For example, to model birds flying through the air, you might write the following rules for the birds:

- If you see a bird close to you, then fly towards it.
- If you are flying near another bird, then try to match its speed and direction.
- If you are too close to the other bird, then slow down or turn away.

Often in these models, surprising behavior results from the interactions of the individuals (in this case, the birds flock together even though one cannot find the 'cause' of the flock in the rules).

In a StarLogo project, a user can see the creatures moving around on the screen and can watch as they interact with one another. He can simulate the complex dynamics of systems and make changes to the underlying rules that result in observable changes in the world. StarLogo is not a domain specific environment. A user can build a model of traffic, birds flocking in the sky, molecules in a container, or foxes chasing rabbits.

But this simple, functional description of the tool does not give a full picture of StarLogo. For us, creating an environment that encourages and supports learners' intellectual curiosity was just as important as providing a new tool for exploring and building models. Just below the surface, StarLogo is a tool that advocates a new kind of teaching and learning, and the fact that it was designed with these issues in mind contributed to our choice of StarLogo as a modeling tool for the Workshops (and subsequent classroom use). The following assumptions describe an ideal context for thinking about patterns and processes in the world through the use of a StarLogo model:

---

[3] This feature is characteristic of an agent-based modeling environment.
[4] We use "turtles" as generic term for individuals in the StarLogo world. This usage is derived from the Logo programming language. Admittedly, "turtles" is not actually a generic term, but we use it to describe ants, birds, and people as well as molecules, cars, and sand, etc.

- People are best able to learn through exploring and constructing models as opposed to listening or reading about systems. This emphasis on construction and exploration grows out of our belief that deep understandings arise when people construct artifacts that are personally meaningful to them (Papert, 1980; Papert, 1993; Resnick & Wilensky, 1995).
- Both intuitive and formal understandings are valuable. In fact, StarLogo enables people to explore the intuitions they have about systems, and through articulating those intuitions, think about more formal ways to describe their understanding (Turkle & Papert, 1992).
- People tend to over emphasize centralization and hierarchy, and underemphasize decentralization and emergence, when conceptualizing systems (Resnick, 1994; Resnick, 1996; Resnick & Wilensky, 1993; Wilensky, 1995). StarLogo enables the creation and exploration of decentralized, emergent systems.
- It is more important for people to deeply understand concepts than to memorize facts. In addition to our reliance on constructionism to help people develop deep understandings, we emphasize the role of collaboration in developing such understandings (Koschmann, 1996a; Roschelle, 1992).
- Learners should have ample time to explore topics of interest, and these explorations will often cross-traditional disciplinary lines. For example, a good way to learn mathematics and computer programming is in the service of accomplishing other goals (Wilensky, 1996).

These assumptions implicitly support a particular conceptualization of teaching and learning—one that is not common in classrooms today. In a school that takes these assumptions seriously, teachers would work together to implement new ideas and new teaching methods in their classrooms. They would develop curricula that support extended investigations and collaboratively develop metrics for assessing student progress. Teachers would assist students in setting and achieving goals and evaluating their progress towards these goals. StarLogo is one of many educational technologies that was created not just for the new computational capabilities that it offers, but also as a platform that supports initiatives that modify the nature of teaching and learning in classrooms.

Embedded Theories of Learning

The list above is predicated on a number of theories of learning. We believe that people learn best when they are constructing their own knowledge and that a particularly good way to construct knowledge is through the creation of an artifact (Papert, 1980). Papert advanced Logo, a programming language designed for children, as a tool to facilitate the realization of his theory. StarLogo is another tool that supports this kind of learning. Encouraging students to collaboratively engage in model building and exploration enhances their learning experience (Resnick, 1987). In addition to enabling explorations of complex, dynamic systems, StarLogo is a tool that aims to facilitate the social construction of knowledge through the design and creation of models.

In choosing to teach teachers to model in StarLogo, we chose both the technical specifications of the tool—its ability to enable users to build and analyze agent-based models—and the associated learning theories of the tool. Throughout the Workshops we strove to define the tool broadly, encouraging participants to think not only about its computational functionality but also about how this tool, and others, can enhance the learning process. Furthermore, just as the technical features of the tool continue to evolve over time, with new releases and enhanced functionality, the associated learning theories evolve as well. We encourage users of the tool, including our Workshop participants, to contribute to both facets of StarLogo's evolution.

Since the tool embraces so much more that particular computational functionalities, there are important consequences for teachers as they learn to use the tool. In particular, learning the technical capabilities of the StarLogo is a necessary but insufficient step towards becoming a member of a modeling culture. The process of model creation provides teachers with an understanding of StarLogo's technical capabilities as well as illustrating the pedagogical practices that we feel will lead to the best use of the modeling tools. At the same time, this experience becomes a concrete point of departure when the teachers transition to debriefing their own learning experience and analyzing the kinds of teaching that the facilitators engaged in. This final process engages teachers in developing strategies for introducing new tools and practices in their own classes. Learning to model, and to think about the world through modeling, is the main aim of the Adventures Workshops. Our belief is that thinking with modeling is a "powerful idea" (Papert, 1980)—one that teachers and students can use to develop deeper understandings of the world around them.

Defining Success

"Successful" integration of modeling depends less on the amount of time that teachers spend using specific tools and more on whether or not they have adopted new theories of teaching and learning that align well with our vision for the tools—or whether our tools support their existing theories of instruction in meaningful ways. As Papert noted, "technology succeeds when it becomes invisible" (Papert, 1990). When teachers use new technologies to support their pedagogical philosophies, their definition of success seems to concur with this notion. In one study of constructivist teachers, Coppola (2000) found that teachers described their success not as adopting new tools but as adopting "new ways of teaching that took advantage of new tools."

This attitude makes it even more important to ensure that the implicit and explicit theories that accompany the tool into the classroom don't get thrown out as the tool gets implemented. Instead, the use of new tools should provide an opportunity to influence teacher practice, both in terms of their approach to teaching ideas and in terms of their choice of what ideas to teach. In the final analysis, the value of technology may reside far more in its ability to engender changes in users' theories of teaching and learning (Fulton et al., 1996) than in the use of the tool itself.

Every Adventures Workshop we run has its own unique character. Through our work with teachers over the past several years, we have identified certain features of participants' experiences that indicate participation in a scientific modeling culture. In particular, we consider the Workshop to be a success for a teacher if, at the close of the two weeks, that teacher is able to:

- *Create and explore models.* We focus on developing teachers' capacities to participate in a modeling culture, a major component of which is developing fluency with modeling tools. We want teachers to learn to express their own ideas through models, but we do not want to have to rely on didactic instruction to help them develop these skills.

- *Discuss and critique models with peers.* We believe strongly in the importance of community and have created specific pedagogical structures that facilitate the development of individuals' abilities to communicate with, teach, and learn from their colleagues.
- *Develop a framework for identifying "good" models.* There are many subtle aspects to learning to build models, including understanding what features to add to a model, deciding how realistic to make a model, assessing the kinds of processes that a particular model enables you to study, and aligning the aims of a model with its content. We concentrate on how models can help people understand patterns and processes, rather than on how models can help them learn specific facts.
- *Build models that generate surprising behaviors.* Many people initially think of modeling as a new medium for illustrating known patterns and processes. We encourage participants to build models whose outcomes they cannot always predict. We want them to appreciate the important role that uncertainty plays in the development of new knowledge.
- *Understand the value of exploring the same system from multiple perspectives.* Through our Workshop structure we engage teachers in thinking about issues through the use of different kinds of models, both on and off of the computer. We want to develop people's abilities to think about patterns and processes through a new modeling perspective, not just by using a new set of modeling tools.
- *Appreciate the relevance of aspects of scientific practice for science learning.* We work to instill in participants an appreciation for the roles of collaboration and public discourse in science, the non-linear, iterative nature of explorations, and the complementary roles that analysis and synthesis play in the development of knowledge—facets of scientific practice that hold promise for science learning but are often not present in science classrooms.

The Adventures in Modeling Curriculum

New technologies, like StarLogo, can shape both what and how people learn. But, too often, people mistakenly believe that the mere presence of a new technology will be sufficient to cause change. The ability to learn new ideas through computer modeling, for example, is greatly influenced not only by the technologies used but also by the ways in which the models are presented. The Adventures in Modeling Workshops are one attempt to explicitly link StarLogo and a set of theories about teaching and learning.

We first introduced a group of students and teachers to modeling at a summer Workshop three years ago, which I co-founded and co-directed (Colella et al., 1999; Klopfer, 2000; Klopfer & Colella, 1999; Klopfer & Colella, 2000). This "StarLogo Community of Learners Workshop" was a collaboration with the Santa Fe Institute (SFI) and was designed to introduce participants to the computational and cognitive aspects of modeling complex, dynamic systems. During the two-week course, participants worked together to design, build, and analyze agent-based models. The Challenge-based teaching model grew out of our ideas for this first Workshop. Since 1998, I have co-directed three of these teacher Workshops, one at SFI and two at MIT (see Appendix A for the latest Workshop agenda). Our team has also supported three student-centered Workshops and an additional teacher Workshop at SFI.

Over time more than seventy teachers have participated in our Workshops. Some of them have gone on to run related teacher and student workshops of their own. Each Workshop uses the materials and a pedagogical structure based on the practices of authentic science and the architecture design studio.

To support the Workshops, and to enable others to create their own instantiations of modeling cultures, we documented the Workshop curriculum and style that we designed and implemented in a book called *Adventures in Modeling: Exploring Complex, Dynamic Systems in StarLogo* (Colella, Klopfer, & Resnick, 2001). This section describes the components of the book, which are a direct outgrowth of the early Workshops and now serve as the curriculum for our ongoing Adventures in Modeling Workshops.

The Adventures book consists of three main sections. The first six chapters explain the philosophy behind StarLogo, introduce modeling concepts, describe the book structure, propose several different ways to use this book, and give a quick tour of the StarLogo world. The core of the book is a series of Activities and Challenges. The appendices in the last section of the book contain annotated links to related Internet resources, notes about other versions of StarLogo, a guide to the StarLogo language, and an explanation of common StarLogo error messages.

One of our primary motivations when we wrote the Adventures book was to achieve a balance between structure and exploration. We designed the materials to foster an exploratory, creative spirit while at the same time providing adequate structure for learning how to build models. In our experience, novices find this structured exploration to be engaging and more tractable than either didactic or completely open-ended learning environments. The design Challenges, off-computer Activities, and pedagogical structure were all created to balance structure and exploration.

Challenges

The Challenges are the pillars of the Adventures in Modeling curriculum. They help learners become familiar with the StarLogo environment and introduce them to the principles of modeling complex, dynamic systems. Each of the ten Challenges poses an open-ended problem and gives learners the tools to design and create a solution in StarLogo. We structured the Challenges to embrace a wide variety of solutions and enable Workshop participants to build coherent and interesting models, even before their developing knowledge of the StarLogo language is complete. At the same time, they build sequentially, with each Challenge focusing on a key concept, like how to move creatures or use variables. This organization enables users to develop familiarity with the StarLogo environment and exercise their model-building skills. The Challenges contain programming hints and pointers to sample projects, which illustrate implementations of the key concepts in the Challenge. This format minimizes the need for direct instruction. Exploring the Challenges helps learners build a broad-based understanding of modeling and a command of the StarLogo language.

Each Challenge is divided up into the following sections:

Challenge	Gives a brief statement of the modeling problem or design goal of the Challenge.
Possible Explorations	Provides a range of extended activities to pursue, each of which relates to the Challenge.
Modeling Concepts	Describes the modeling principles that are addressed in the Challenge.
StarLogo Concepts	Describes the key StarLogo ideas that are introduced in the Challenge.
Challenge Philosophy	Situates the Challenge within a broader modeling context.
Challenge Description	Provides further details about the goal of the Challenge.
Challenge Guidelines	Supplies specific StarLogo programming information and illustrates possible Challenge solutions or related ideas with sample projects.
Tips for Teachers	Concludes the Challenge with a recap of major concepts covered and evaluation tips for teachers.

Every Challenge comes with associated StarLogo projects, which are described in the text, but best explored in StarLogo. We do not present all of the information in a Challenge to participants. Instead, we integrate some information from the Challenges, including the philosophy behind the Challenge, analogies to real systems, and evaluation criteria, into our introductory discussions.

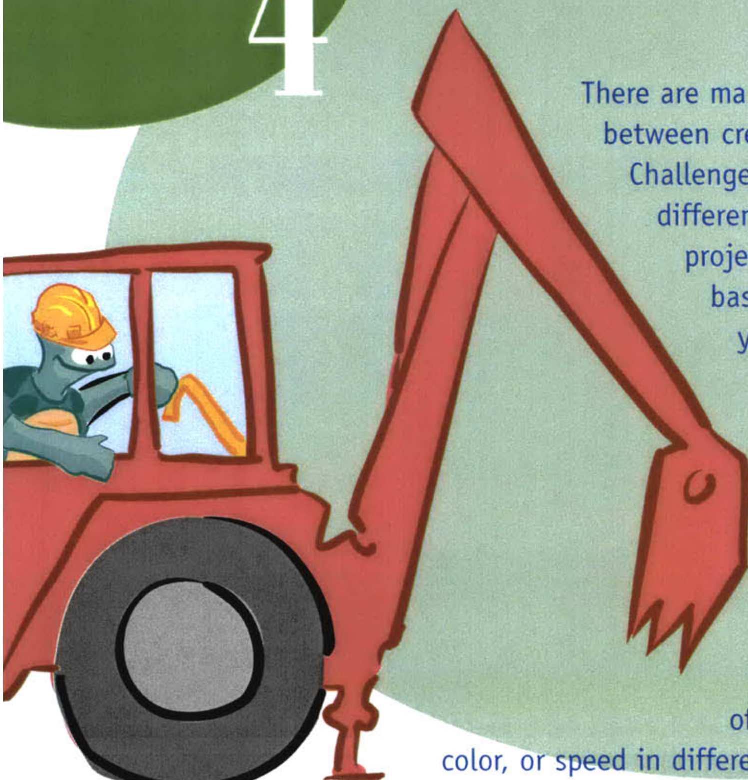
We begin the Challenge by introducing the main modeling and StarLogo concepts. Because the relevant programming information is contained in the Challenges, it is not necessary, and can be counterproductive, to deliver a lengthy introduction. We have found that demonstrating some of the features of a single sample project can be an effective introductory technique. In some of the later Challenges, we begin with an exploration of real-world systems that exhibit some of the interactions that participants are modeling.

A Sample Challenge

Challenge 4, on the following pages, was given on the third day of the Workshop. It comes with five associated sample projects, Bumper Turtles, Big Bumper Turtles, Yellow Brick Road, the Tortoise and the Hare, and Follow the Leader, three of which were produced as Challenge solutions in previous Workshops.

CHALLENGE 4

Turning Turtles Into Termites



There are many types of interactions that can occur between creatures and their environment. In this Challenge, you can choose to model one of two different types of interactions. You can create a project in which turtles alter their behavior based on environmental characteristics, or you can design and build a project in which turtles change their environment.

If you choose the first option, then create a project in which the environment influences the turtles in more than one way. Start by thinking about new ways that the environment can change turtle behavior. You might build a world of patches that affect the turtles' position, color, or speed in different ways. Your project should be more ambitious than the one you completed for Challenge 3. To see an example of this kind of project, check out ***Speeding Bumper Turtles***.

If you choose the second option, then build a project that asks the turtles to manipulate the patches in their environment. Perhaps your turtles will "move" objects (represented by patches) as in the ***Turtledozers*** or ***Termites*** projects. Alternatively, your turtles could change the patch colors as they walk across the **Graphics Canvas**. You can explore how these modifications to the environment change the turtles' behavior.

POSSIBLE EXPLORATIONS

- Try programming the turtles to draw paths in colors that also influence their movement.
- Experiment with combining turtle and patch activity. Perhaps patches of a certain color influence turtles and turtles change the color of each patch they walk across.
- What happens in your project if the patches change color randomly?
- See what happens if turtles multiply when they run into certain patches. Are the effects of **hatch** and **sprout** identical?
- Explore the results if patches affect absolute headings instead of relative headings.
- Think about some real-world systems in which living things interact with their environment. Try to incorporate some of those ideas in your project.

CHALLENGE PHILOSOPHY

In Challenge 3, you started to think about ways in which the environment can influence the behavior of individuals. Now you can begin to consider scenarios in which individuals also influence the environment. For instance, beavers build dams, changing the course of rivers; people cut down forests, altering the amount of available light and potential habitats; and termites eat wood, dramatically changing the stability of the original structure.

Often the changes that individuals make to their environment in turn influence the behavior of those same individuals. Imagine a teenager who doesn't pick up his dirty clothes. The more clothes that accumulate on the floor, the bigger the cleanup job that he faces, and the less likely he is to pick up all of his clothes. In this Challenge, you will learn to combine the effects of individuals on their environment with the effects of the environment on those individuals.

In the previous Challenge, a simple mechanism (**check-patches**) allowed the turtles to react to objects in the environment. If a turtle saw a blue patch in front of it, then it turned right. This Challenge introduces a mechanism for the turtles to manipulate their environment, allowing you to explore two-way interactions between the patches and the turtles.

There are two possible strands to follow in this Challenge. The first strand requires you to think creatively and devise new ways for the environment to affect turtle behavior. During this process, you will be able to explore the states (**color**, **heading**, etc.) of individual turtles. In the second strand, you will design and implement turtle behaviors that alter the environment. The ability to produce interactions between individuals and their environment opens the door to an incredibly rich area of modeling. The sample projects and commands provided in this Challenge only scratch the surface of possibilities. Feel free to explore these types of interactions at length, but remember that the parallel nature of StarLogo causes the complexity of your project to increase rapidly, so it is always better to start with a simple idea.

MODELING CONCEPTS

- Investigate ways that individuals can alter their environment.
- Understand how the environment can affect the behavior of individuals.
- Relate communication between individuals and their environment to real-world systems in which agents' interactions with the environment are important.

CHALLENGE DESCRIPTION

In this Challenge, you explore complex interactions between turtles and their environment. You can implement new ways that the patches can affect turtle behaviors or program the turtles to change their environment. As you explore these two options, you can also think about ways to combine turtle and patch activity. Before you begin programming, think about the kinds of environmental changes you would like to implement and how turtle actions might, in turn, be impacted by those changes.

STARLOGO CONCEPTS

- Learn simple commands that enable patches and turtles to communicate.
- Experiment with feedback between the turtles and patches.
- Teach turtles to change features of the patches that they occupy.

The sample projects in this Challenge contain combinations of interactions between turtles and their environment. As you think about different ways that turtle behavior can be influenced by the environment, you can explore the sample project ***Speeding Bumper Turtles***. As you consider ways that turtles can change their environment, take a look at ***Turtledozers***. The ***Termites*** project demonstrates how a StarLogo model can capture some elements of real-world systems.

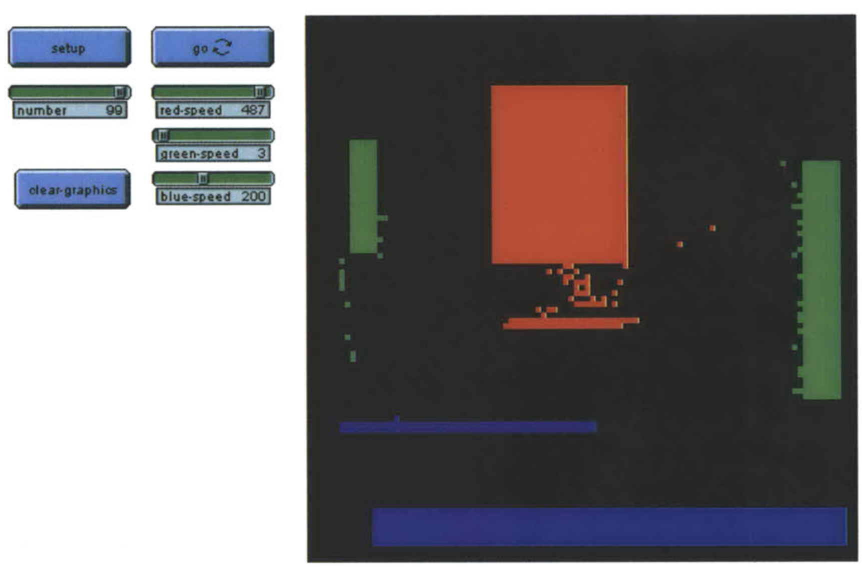
CHALLENGE GUIDELINES

By now you should be comfortable building a simple StarLogo project from scratch. In this Challenge you are not provided with a preprogrammed starting project or piece of StarLogo code. Please be aware that it is perfectly OK—and sometimes preferable—to copy parts of past projects or simply look at their code if you find it helpful. In fact, that's why StarLogo was designed with visible procedures, even for the sample projects.

You have already encountered interface elements and many of the commands that you will use in this Challenge. A few new patch-related commands are covered below to help you create rich interactions between the turtles and patches. You might want to check out some of the sample projects before you get started on the Challenge. The first project demonstrates a new way to change the turtles' responses to their environment. The other two projects illustrate different ways that turtles can alter their environment.

Speeding Bumper Turtles

This project introduces the simple use of sliders to control how the turtles react to obstacles in their environment. In any model, sliders control values that anyone can easily change. Often, even a small change in a slider will cause a noticeable change in how the whole system looks or behaves.



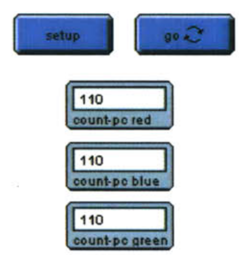
The Speeding Bumper Turtles project.

Speeding Bumper Turtles is similar to the ***Bumper Turtles*** project in the previous Challenge, except that in this project the turtles' speeds change every time they bounce off of a colored obstacle. The speed associated with each obstacle is determined by the corresponding slider value. Take a look at the procedures to see how this behavior is implemented. Remember, every time you see **red-speed**, **green-speed**, or **blue-speed** in the procedures code, the program is reading the current value from the corresponding slider.

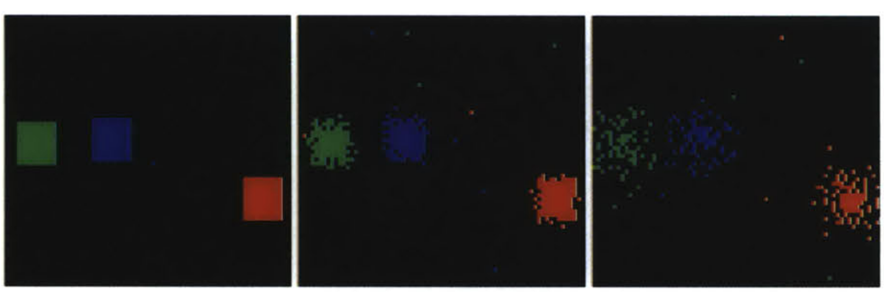
Click the setup button to set up the turtles at their initial positions. Click the go button to start the simulation. At any time, you can change the value of each of the speed sliders, green-speed, red-speed, and blue-speed. The value of each slider determines the speed that the turtles assume after they bounce off of a colored patch. You can also set the number slider to determine the number of turtles in the project. This change takes effect only when you setup the simulation again. If you want to draw a new set of obstacles, press clear-graphics and draw new obstacles using the **Paint Tools**. According to the existing procedures, the obstacles need to be blue, red, or green for the turtles to react to them, but you can make the obstacles in any shape or location that you wish.

Turtledozers

This project is another variation of ***Bumper Turtles***. Press setup to draw three randomly placed colored squares on the screen. If you want to, you can supplement these squares with additional drawings that you make using the **Paint Tools**. In ***Turtledozers*** the **check-patches** procedure has been modified so that when the turtles bounce off of an obstacle they drag a piece of it with them for one step. This turtle action disperses the obstacles. The three monitors keep track of the number of red, blue, and green patches. As the turtles disperse the obstacles, the number of colored patches eventually decreases. Why do you think that this happens?



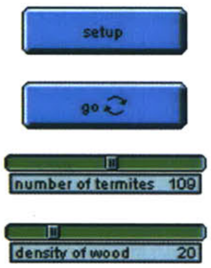
The Turtledozers' Interface.



Turtledozers' Graphics Canvas over time.

Termites

This project is an idea model that was inspired by the behavior of termites gathering wood chips into piles (see Chapter 2 for more on idea models). Though the project does not capture all of the complexity of real termite behavior, it does allow you to visualize one simplified aspect of termite behavior—mound building.

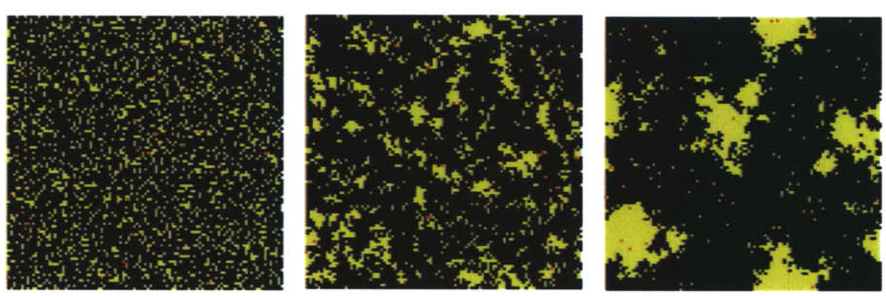


The Termites' Interface.

Click the setup button to set up the termites (red) and wood chips (yellow). The number slider controls the number of termites, and the density slider controls the initial density of wood chips. (Note: Changes in the number and density sliders only take effect when you press setup.) Click the go button to start the simulation. What happens to the distribution of the wood chips? What happens to the number of piles? Over time some piles disappear as termites carry away all of the chips. However, there is no way to start a new pile from scratch, since termites always put down their wood chips near other wood chips. Therefore the number of piles has to decrease over time.

What rules do you think the turtles are following? You might think that the termites would need a complicated set of rules to build piles. In fact, these termites follow a set of simple rules. Each termite starts wandering randomly. If it bumps into a wood chip, it picks the chip up and continues to wander randomly. When it bumps into another wood chip, it finds a nearby empty space and puts its wood chip down. (Notice that the wood chips are represented as colored patches. The appearance of movement comes from the termites updating the patch colors as they pick up and put down the wood chips.) As piles of wood chips begin to form, the piles are not "protected" in any way. That is, termites sometimes take chips away from existing piles. That strategy might seem counterproductive. Can you imagine what would happen if the piles were protected? How would you establish which piles should be protected?

The termites in this project employ a decentralized strategy to pile up the wood chips. There is no termite in charge and no special predesignated site for piles. In fact, the termites know nothing about creating large piles of wood chips. The termites only know how to set a single wood chip down next to another one. Each termite follows a set of simple rules, but the colony as a whole accomplishes a rather sophisticated task.



The Termites' Graphics Canvas over time.

Asking Turtles and Patches

In StarLogo, all three characters, the turtles, the patches, and the observer, can communicate with one another. In addition, the observer can ask the other two characters to perform tasks. For example, it is often convenient to run a setup procedure from the **Observer Procedures Pane** that creates turtles and then asks them all to set their heading to 90, using **crt 100 ask-turtles [seth 90]**. In this case, the observer is asking all of the turtles to run the **seth 90** code. Similarly, the observer can ask all of the patches to change their color to red, using **ask-patches [setpc red]**. The observer is the only character that has this power; **ask-patches** and **ask-turtles** cannot be called by the turtles or the patches, and should be typed only in the **Observer Command Center** or **Procedures Pane** [14].

Here are some new commands that you may find useful as you create your own project.

If you want to...	Use these commands:	For this character:
Have a turtle set the color of a patch that it is on	Use the command **stamp *newcolor*** to change the color of the patch to ***newcolor***, where ***newcolor*** is either one of the basic color names or a color number.	
Change the color of the patches	Use the command **setpc *newcolor***. For example, you could type **ask-patches [setpc blue]** or **ask-patches [setpc 101]**.	Note: This command must be called from within an **ask-patches** statement. [14]
Have new turtles "born" on a patch	Patches can create turtles using the **sprout [*statements*]** command. The ***statements*** are any commands you wish to give the newborn turtles. You can specify that only certain patches create turtles. For example: **ask-patches [if pc = 15 [sprout [setc blue]]]** creates blue turtles on patches whose color equals 15.	Note: This command must be called from within an **ask-patches** statement.
Have turtles "give birth" to new turtles	Turtles can create new turtles using the **hatch [*statements*]** command. The newborn turtle is identical to the "mother" turtle. You can give specific commands to the new turtle in the ***statements***.	

CHALLENGE HINTS

TIPS FOR TEACHERS

Challenge 4 suggests two different strands for students to pursue. The first, creating new ways in which the patches influence the turtles' behavior, is suitable for students who are still mastering some of the concepts from Challenge 3. Encourage these students to fully explore this aspect of the Challenge. This process will help to increase their proficiency with StarLogo without causing them to fall behind. If they are interested in manipulating the environment, but not quite ready to move to the second strand, they can make use of the **Paint Tools** to create an appealing environment for their project. Other students who may choose this first strand are those who had a great project idea during Challenge 3 but were unable to fully implement it in the time that they had. The second strand, instructing the turtles to change aspects of the environment, is good for those students who are comfortable with many ways that turtles can react to the environment and are excited about adding new kinds of behaviors to their models.

As students design, build, and present their projects for Challenge 4, ask them to think about the people who will use their projects. Are their ideas clearly communicated by their models? Do their projects attempt to address too many issues? Have they incorporated ways for people to interact with their models? If so, do these interactions illuminate the core ideas of their projects? Could a user understand and explain these core ideas? While not all students will be at this stage, your input can help them begin to consider these aspects of design. You can ask them to include instructions and explanations for using their projects in the **Information Window**.

Up until this point, students' flexibility in the StarLogo environment was limited. Now they know enough to build projects based on ideas that they have rather than just exploring a very basic set of commands. From now on, it is possible for you to customize the Challenges for your curriculum. When you hand out the Challenge, give students some ideas or sample solutions that are appropriate for your subject area. Ask them to address some domain-specific questions during their work-in-progress reports. See Chapter 5 for some ideas about customized projects. If you would like to find out more about how other teachers are adapting the Challenges for their classes, send email to the **starlogo-users@media.mit.edu** mailing list.

Challenge Solutions

The most significant feature of the Challenges is their balance between structure and open-endedness. By articulating a specific design goal, they provide a common direction for learners to take as they build solutions. This commonality ensures that students will be able to learn from each other's solutions because they will have some common ground. At the same time, the Challenges do not overly constrain the kinds of solutions people can create, allowing students to pursue ideas of interest to them. 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. This ability to embrace a wide range of solutions is helpful as people begin to model, because it enables them to pursue an idea they have. It is also a critical component of our modeling culture—we work hard to ensure that models are understood as tools that can help people investigate and explore patterns and processes that interest them. The Challenge structure allows us to emphasize this component of the culture by example from the very beginning of users' interactions with StarLogo.

When we present the Challenges, we find that learners' styles vary—some like to jump right into the Challenge by starting their own project from scratch, while others choose to try out the sample projects, which illustrate some of the principles of, and possible solutions to, the Challenge. Exploring and modifying the sample projects can help people generate ideas for their own projects and develop a better understanding of the underlying mechanisms that produced the observed patterns. The Challenges and sample projects are designed so that both approaches—creating a new project or building on a sample project—are good learning experiences.

Throughout the Challenges participants are building familiarity with the StarLogo environment and with the uses of modeling. Many specific examples of their learning processes are covered in subsequent chapters. Here, we provide a few actual Challenge solutions in order to give a concrete example of the variety of projects people design and create for each Challenge. Whether or not participants chose to start with the sample projects, the open-ended nature of the Challenges encourages a wide variety of solutions. The diversity of solutions is evident in the following projects constructed in response to a Challenge on interactions between agents and their environment. These are just three of over seventy projects that we have seen, 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.

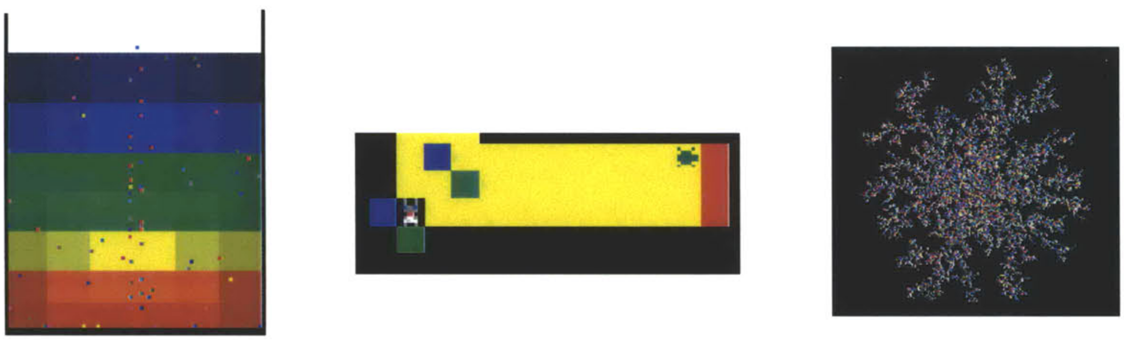


Figure 1a-c: Three solutions from Challenge 4 (from left to right). Convection (a), tortoise and hare (b), and aggregation (c).

Activities

Though "on-screen" computer modeling is one focus of the book, "off-screen" Activities provide another way to connect abstract notions of dynamic processes and complexity to personal experience. The Activities are group exercises that help participants gain an alternate perspective on concepts like exponential growth, local versus global information, and group decision-making. For instance, in one Activity, participants "fly" around a field trying to form cohesive "bird flocks" without the assistance of a leader. The Activities engage groups of people in life-sized simulations, enabling people to participate in and "see inside" of a dynamic system. This viewpoint enables them to reflect on both their own individual experiences and the behavior of the whole system. These group exercises help participants develop deep understandings and draw connections between computer models of complex systems and their own real-life experiences with similar systems (Ackermann, 1996; Colella, 2000; Wilensky & Stroup, 1999). When interwoven with the Challenges, they provide an opportunity to explore modeling from different perspectives, which each appeal to different learning styles.

Each Activity is divided up into the following sections:

Modeling Concepts	Describes the modeling ideas that are illustrated through the Activity.
Materials	Lists the items required to run the Activity.
Running the Activity	Designed for the instructor, explains how to conduct the Activity.
Facts for Facilitators	Provides additional tips for facilitating the Activity.

Unlike the Challenges, no part of the Activity write-ups is handed out ahead of time. Many of the Activities depend on inventing and adopting strategies during the Activity. The Activity write-ups often include information for the facilitator about optimal strategies for individuals, the underlying rules of the model, or the theoretical basis for the Activity. We find that the Activities are far more effective learning tools if the participants are able to discover these principles through their experience during the Activity and subsequent discussion, rather than by reading about them ahead of time.

A Sample Activity

Workshop participants experienced The Flight of the Humanboids, presented on the following pages, on the third day of the Workshop.

ACTIVITY 9

Flight of the Humanboids

When people see a flock of birds flying or a school of fish swimming, they often assume that there must be a leader. When that same flock or school reacts to a predator in a strikingly coherent fashion—almost as if it were a single large organism—it seems even more likely that a leader is in charge of the group's movement. In fact, flocking patterns typically arise without a leader. Many other patterns in nature arise in the same way, through decentralized interactions among individual animals.

As swallows dart through the sky, they often fly in a tight formation. Yet, you never see two swallows crash into one another. During the flight, each bird follows a set of rules designed to maintain an appropriate distance from the other birds. They want to be close to the other birds, but not too close. By transforming participants into bird-like creatures called "humanboids," this Activity demonstrates how coordinated behaviors can develop from simple rules that each member of a group follows. In order to form a flock, the humanboids will need to determine a suitable set of flocking rules.

MODELING CONCEPTS

- Create patterns without relying on centralized control.
- Design and test some flocking rules.
- Learn how flocks can adapt to changing environmental conditions.

MATERIALS

- A large open space
- A place to record the rules

RUNNING THE ACTIVITY

Ask the group to determine a set of flocking rules. These rules might contain instructions specifying what to do if you get too far from other humanboids, how to avoid collisions, or how to respond to obstacles. You might suggest that participants consider the attributes of a flock, like spacing, speed, heading, and so forth. Write the rules down on paper. This process helps disambiguate the rules and ensures that everyone in the group has agreed on each of the rules. Note: It is possible to come up with hundreds of rules to control flocking behavior. Remind the humanboids that they will need to follow these rules, so it is best to agree on a few general rules that everyone can remember and execute.

When a set of rules is established, send your flock to a large open space (preferably a gymnasium or an outdoor space) and ask them to fly. There should be no verbal communication between humanboids while they are flocking. Let the flock run for several minutes. Did the rules work right away? Did they break down (or begin to work) over time?

Regroup the flock so that they can discuss their flocking behavior. They might want to consider the following questions:

- Were the rules adequate to generate flocking behavior or was there improvisation during the Activity?
- Which rules were most important or effective in forming the flock? Is there anything special about these rules?
- Did one or more people take a leadership role? How did this affect the implementation of the rules?
- Would the rules be adequate to avoid a stationary obstacle? How about a predator?
- What would happen to their flock if one humanboid suddenly dropped out?

Ask the group to come up with a revised set of flocking rules and return to an open space to fly. Did the new or additional rules prove to be more effective? The group might want to try some advanced flocking behavior such as predator or obstacle avoidance or the formation of specific patterns (V shapes, wide or narrow groups, etc.). What kinds of rules are needed to achieve these kinds of flocking behaviors?

FACTS FOR FACILITATORS

The humanboids might initially have a hard time forming coherent flocks. Encourage members of the group to revise their flocking rules if they think this will improve the formation. (But try to do this as a group, rather than allowing a dispersed flock to fly while individual humanboids spontaneously alter their behavior.) It can take several iterations to create a recognizable flock.

In other cases, participants succeed in forming a flock, but only by "cheating" (even if they aren't aware of it). Rather than rigorously following the rules they agreed upon, they might improvise on the fly. You should emphasize the importance of sticking precisely to the agreed-upon rules.

Sometimes, the difficulty of decentralized flock formation leads the humanboids to conclude that flocks cannot form without a leader. If this situation occurs, encourage them to consider alternative explanations. How carefully and consistently were they following their flocking rules? Do they believe that their rules were sufficient to form a flock? (How could they test this belief?) What new rules would they add to improve their flocking behavior? The lives of some birds depend on their flocking ability. These birds must follow good flocking rules or risk death. Could participants devise and follow a more effective set of flocking rules if there were negative consequences for straying from the flock? To simulate these consequences, you can "prey on" straying humanboids by removing them from the flock.

You might discuss how flocking rules originated. Does each group of birds have a fixed set of flocking rules, like the humanboids did? Or do the rules evolve over time?

Craig Reynolds is the original creator of computerized birdlike objects, called "boids." His boids model coordinated animal motion such as bird flocks and fish schools. See http://www.red3d.com/cwr/boids for more information. For related activities check out Schools are for Fish at http://www.meas.ncsu.edu/outreach/fish_school.html.

A Pedagogy of Modeling

The Activities and Challenges are interwoven during the Workshops because they are complementary classroom exercises. The Activities use diverse materials to facilitate the exploration of agent-based modeling concepts from different perspectives and to foster a deeper understanding of individual and systemic behaviors. In most cases, the Activities and the Challenges are not explicitly linked to one another. In fact, unlike the Challenges, the Activities need not be conducted in any particular order. Alternating between Activities and Challenges not only gives students an opportunity to reflect on what they are learning and discuss the nature of dynamic systems, but also engages students with different learning styles.

In a typical Workshop, we begin with an Activity. Before commencing the Activity, we give students (who are almost always teachers themselves in our Workshops) instructions about the mechanics of the Activity, and we highlight particular behaviors, strategies, and dynamics, which they might want to watch for. The Activities themselves take between ten and thirty minutes to conduct. First, we allow students to try the Activity once and then lead them in a discussion of their observations and initial ideas about the Activity. Following that discussion, we introduce an intervention (often students suggest valuable interventions) and allow them to rerun the Activity and observe the new dynamics. The post-activity discussions can be quite lengthy, so we try to gently direct the students towards the central concepts of the Activity. Often, the facilitator must decide when to wrap up these conversations. We typically close the Activity when we feel that all of the participants have explored the central concepts, though the goals and constraints of the setting influence the timing of that decision.

After the Activity, we introduce a Challenge. We find that a very short description of the Challenge is often sufficient to get students started. We strongly recommend that students work on the Challenges in small groups. We allow students a couple of hours to complete a Challenge (the earlier Challenges often take less time). We sometimes stretch a single Challenge over multiple days and engage students in Activities or other classroom exercises in between work on the Challenge. As students are working on the Challenges, we circulate around the room and check on the progress of each group. During these conversations, we ask students to describe what they want their models to show, reflect on how well their models achieve this goal, and think about the next steps that they want to take. We also assist students with technical or conceptual difficulties that they have encountered; however, we encourage them to seek help first from other groups.

About two-thirds of the way through each Challenge (though this can be done at the end of the Challenge if necessary), we gather all of the students and ask each group to make a brief presentation about an interesting facet of their model. These progress reports allow students to show their work without the pressure of presenting a final project. We pay special attention to how well their models communicate ideas to other people. After each group's presentation, facilitators, guests, and other students all give feedback to the model builders, enabling them to revise and improve their models in the remaining class time.

Creating a Learning Environment

A key element to the success of exploring the Challenges and Activities during the Workshops is creating the appropriate learning environment. Ideally, the environment should provide adequate freedom balanced with appropriate feedback.

Adequate freedom can mean:

- Having enough time to fully explore the Challenges.
- Being able to pursue a variety of solutions to a single problem.
- Having ample physical space to diagram ideas.
- Enjoying opportunities to explore ideas through non-traditional learning activities.
- Being free to consult with peers and work in teams in a "relaxed" social environment.

Appropriate feedback can entail:

- Instituting mechanisms to provide constructive, generative suggestions.
- Facilitating peer-to-peer conversations about projects.
- Helping students make connections to underlying modeling and programming concepts.
- Discussing the goals of a project.
- Presenting projects to larger communities for external review.

There are many ways to engender this kind of environment. We have chosen to adapt features of the architecture design studio to create such a learning environment.

Adapting the Architecture Design Studio

There is a long history in architecture education of structuring learning environments through design challenges that are solved with input from classmates and teachers. We structure teachers' work on the Challenges in a similar fashion by adapting two key components of the architecture design studio: a format for informal student-teacher interactions, called a desk-crit, and the public presentation of work-in-progress, called a pinup (Colella et al., 1999). These mechanisms provide learners with generative feedback during the design and building processes.

During our desk-crits, we encourage teachers to describe what they wanted their models to show, to reflect on how well their models achieved these goals, and to think about the next steps they wanted to take. Desk-crits are quite like the combination of questioning and assistance that teachers provide as they walk around their classrooms while students are working on problems. During the Workshop, we periodically ask the teachers to pair up with another group and give desk-crits to each other. This process is important because the questioning (from the facilitator) that occurs during a desk-crit is designed to help the learners think through their problems and articulate areas of particular difficulty. Desk-crits are not simply an opportunity for students to ask questions and facilitators to answer. We have found through experience that these are skills that take practice.

The pinups provide a public forum for participants to articulate the rationale behind their models. In a pinup, each group presents their solution to a specific aspect of the Challenge. They share their successes and failures and describe insights they have had. Participants can use pinups as an opportunity to discuss specific modeling techniques or discuss higher-level aspects of their models, such as how well a model allows them to think about a problem. The pinups are an invaluable source of information exchange and idea construction during the Workshops.

Though the structure outlined above has been very useful, we have found that the pinups can run too long (we try to keep the presentations to fewer than three minutes each, except for the final presentation of the semester or Workshop). All types of "students," from younger children to experienced teachers, occasionally try to describe every aspect of their model instead of focusing on a specific idea or issue. To address this problem, we sometimes ask the groups to spend a few minutes presenting their work to another group, instead of to the whole class (a modified desk-crit). Alternatively, we ask people to write answers to a few focused questions before their presentations. The Tips for Teachers section of the Challenges are designed to help teachers generate these questions.

Incorporating pinups and desk-crits can foster creative thinking and cognitive mastery, while at the same time providing a structure that supports community-based learning through design tasks. We find that using informal interactions and public presentations to organize the Challenges enables teachers (and students) to develop both the abilities to design, implement, and explore models and the facilities to describe, analyze, and critique models (Kafai & Ching, 1998; Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998; Shaffer, 1998). It is these skills that enable teachers—even those with limited backgrounds in science and technology—to participate in a modeling community.

Methodology

In July 2000 we ran the fourth Adventures in Modeling Workshop.[5] During the course of the Workshop, teachers learned to:

- Deconstruct model systems
- Experiment with models
- Design and create their own model systems
- Evaluate models

The Adventures in Modeling Project uses qualitative research to determine how we can engage teachers in authentic science practices and how those experiences can influence their teaching practice. By analyzing data collected at the Workshops, we can learn more about how teachers build the technological and scientific fluencies necessary to undertake authentic scientific investigations. By documenting teachers' experiences in their classrooms, we can begin to understand how, when, and why teachers choose to integrate new tools and ideas into their classes.

Extensive and varied data were collected from before the Workshop commenced through the beginning of the spring term of the teachers' courses. One crucial source of data for the study was a complete videotape log of all of the pinups, group discussions, and Activities during the

[5] The names of the Workshops have changed over the years.

Workshop. We also collected pre- and post-Workshop surveys (see Appendices B and C) and kept field notes, including interpretive notes, on both group and individual conversations throughout the Workshop. In addition, we catalogued all modeling projects.

Through an analysis of the videotapes, teachers' projects, and field notes we established a framework for characterizing teachers' experiences in the Workshop. This framework enabled an exploration of the ways in which they learn about modeling, the influence of multiple forms of media, and the development of a community of practice—in short it enabled the analysis of the design and development of a modeling culture.

After the Workshop, we profiled four teachers, visiting their schools and classrooms for between fifteen and thirty-five class periods each. The selected group of teachers represents various levels of classroom integration—from conducting extensive model building activities to incorporating a limited number of modeling approaches. During this time, we collected email correspondence between teachers related to this project, videotape segments from classroom observations, interview responses and videotaped group discussions with teachers, field notes from classroom observations and informal conversations with teachers, and all projects that teachers and their students worked on.

These case studies highlight the extent to which teachers choose to integrate modeling and related activities into their classes. In particular, they illuminate:

- How teachers decide to make changes in their teaching.
- What influence their Workshop experience has on those decisions.
- Which materials they choose to use, and why.
- Which teaching strategies they choose to adopt, and why.
- Whether or not modeling proves to be an effective vehicle for integrating aspects of authentic scientific practice.

The data collected during this phase of the project helped develop a rich understanding of teachers' choices regarding the integration of new materials and methods into their courses.

Participants

In this study, we focus on a group of teachers who came to a two-week StarLogo Workshop at MIT in the summer of 2000.[6] Twenty-two educators attended the Workshop. This section contains specific information about the group of educators and their motivations for attending the Workshop.

Teacher Profiles

Seventeen of the participants were classroom teachers, one was a curriculum coordinator, one was a media specialist, two were technology coordinators, and one was interested in education (and is now teaching) but had not previously held a position in a school. The classroom teachers came from a variety of subject areas including elementary (1), language arts (3), mathematics

[6] In addition to observing teachers from the 2000 Workshop, I observed one secondary school computer teacher from the first (1998) Workshop who taught a modeling course for the first time in the fall of 2000.

(3), social studies (1), science (8), business (1), and computer specialists (3). Teachers taught various grade levels including kindergarten (1), 4th-6th (4), 7th-8th (7), and 9th-12th (10).

Our group of teachers had a wide range of teaching experience. Six of the teachers had been in the profession for 1-5 years, two for 6-10 years, 1 for 11-15 years, six for 16-20 years, and six for over 20 years. Similarly, they had different levels of education: BA/BS degrees (3), BA/BS + 15 credits (2), Masters degrees (7), Masters + 15 credits (7), and Doctorate degrees (3).

Finally, nine of our participants were female and thirteen were male.

Reasons for Attending the Workshop

We specifically designed the Adventures in Modeling Workshop to appeal to people without any experience in computer programming or modeling. The teachers who attended the Workshop fit this profile. Most of the participants had little prior experience with computers. Over half of the teachers reported using no curricular software in their classes during the previous year.[7] The teachers reportedly spent an average of 15 to 45 minutes per week on course-related Internet surfing in the previous year, and their students spent an average of just over 15 minutes per week using a computer in their classes.

Despite this lack of technology background, many teachers expressed interest learning about technology, both for themselves and for their classes. They were attracted to the Workshop for a wide variety of reasons including:

- [My] desire to use technology in a coherent and directed way.
- [My desire to] teach students to think in systems.
- [My] anticipation that StarLogo will be something that teachers would like to use with their students.
- The opportunity to develop curriculum-relevant tools that will foster higher-order thinking in my students.
- [My desire] to teach/use a programming language in my science courses and expand my use of technology.
- The opportunity to enhance my skills in an area that would be beneficial to my students.
- [My] need to bring new projects into my classroom [that will] utilize the computers I have available. (pre Workshop survey)

However, the lack of computer experience weighed heavily on some people's minds coming into the Workshop. Ten of the participants mentioned lack of programming experience or comfort with technology as their biggest concern about the Workshop. Julie's concerns were typical: My biggest concern is that "my limited technology skills will be put to the test."[8]

As we will explore in the next chapter, the Workshop structure adequately facilitated mastery of modeling technologies and ideas for most teachers, even for those who had very little background in technology. Yet, participants' own previous skills and knowledge also influence their Workshop experience. The ways in which we can influence teachers' conceptions of modeling are both a function of their previous knowledge and constrained by that same knowledge.

---

[7] Pre Workshop survey.

[8] Pre Workshop survey.

4. Cultivating a Modeling Culture

It is a sunny afternoon on the second day of the Adventures in Modeling Workshop. Teachers are gathered on the great lawn of MIT, each of them holding a piece of crumpled up paper. One teacher is called to the front of the group, and the rules of the "Survival of the Fittest Paper Catchers" Activity are explained:

- If you are standing at the front of the group, then throw your paper high in the air when the facilitator gives the "next generation" command.
- If you catch your paper, then you survive and may "reproduce" by calling up another teacher to join the population.
- If you don't catch your paper, then you "die" and must sit down.

The first teacher throws her paper and catches it. She calls up a colleague, and they both catch their papers. Soon, the population grows to four people and then eight. On the next round, two teachers drop their papers and the rest reproduce, resulting in a population of 12 people. The available pool of people to call up declines and the population reaches a maximum when it reaches the total group size of 22 teachers.

Figure 2: Teachers playing Survival of the Fittest Paper Catchers, with the facilitator recording population size over time.

When the population stops growing the teachers stop to discuss the growth of the population. One person suggests that it resembles exponential growth, while another says that is looks like the population "levels off" at 22 people, and someone else comments that this process is logistic (or S-shaped) growth. We talk about other populations that grow in similar fashions. Another teacher comments that throwing the papers up and catching them is like selection, except in this case people seem to be able to make adaptations (by improving their paper catching skills) during a single "lifetime".

We decide to play again, but we change the game a bit by placing a small piece of newspaper on the ground and introducing a new rule:

- Each member of the population must have part of one foot on the newspaper at all times. Removing your foot from the paper (even for an instant) results in "death" (sitting down).

This time, the first teacher gets flustered and drops his paper, leading to a population crash. We play one last time. The first teacher catches his paper and calls up a colleague. They throw their papers and the population increases to four people. Now, the paper is getting crowded. Next

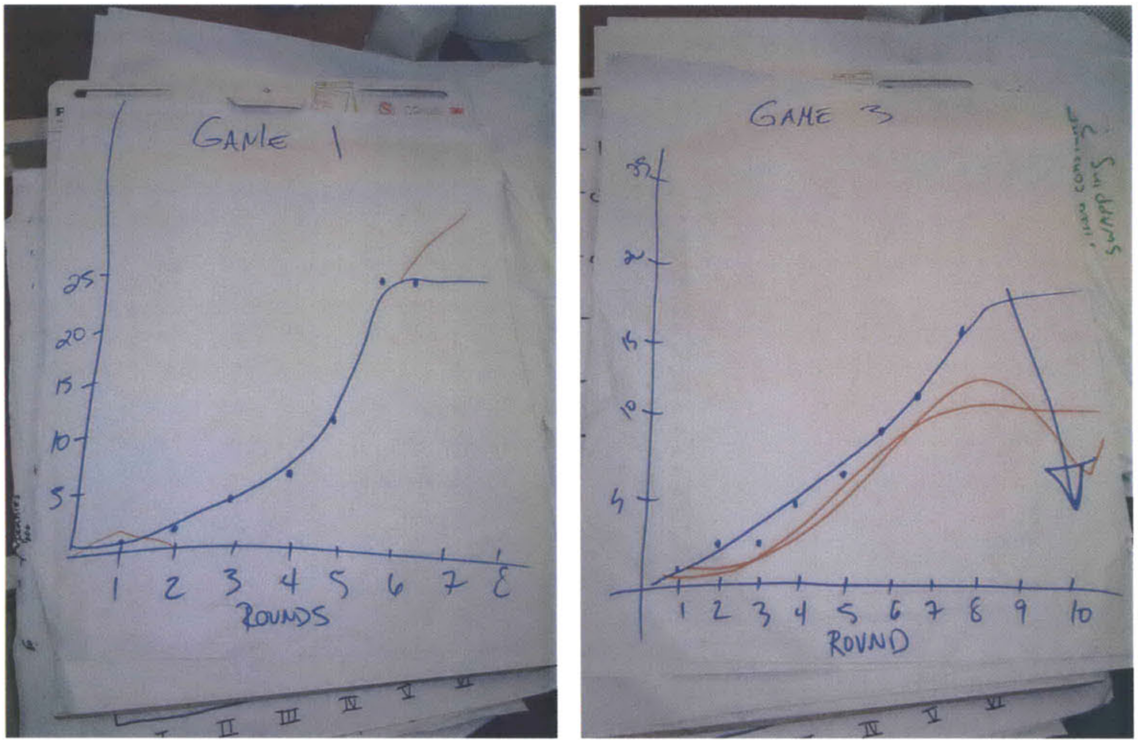


Figure 3a-b: In the first game of Paper Catchers (a), the population grows exponentially until all of the teachers are members of the population (the blue line). The orange line in the upper right-hand corner shows teachers' hypothesis of population growth if the pool of potential members was larger. In the second game, shown in orange on the lower left-hand corner of (a), the population crashes after one round. In the third game (b), the population grows until it reaches the 'carrying capacity' of the newspaper, when it either crashes (blue line) or begins to oscillate around the carrying capacity (orange line).

time, some teachers catch their papers but a few miss, and the population size changes slightly. Each round, I track the size of the population. Eventually, the paper is too crowded and the population stabilizes around ten people.

After the games, the group gathers to discuss the growth of their population. The teachers articulate how the additional constraint of the newspaper changed the dynamics of the game. One teacher compares the newspaper to a limited resource in a real population, like habitat. Another comments that catching the paper might have been more of a selective force if members of the group had found it more difficult to accomplish. A conversation ensues about other variables, including food, shelter, and water, that the paper could represent. As the debrief winds down, we head upstairs to explore some StarLogo models of population growth and decline.

Defining a Modeling Culture

During the development and refinement of the Adventures in Modeling Workshops, we have shifted from an initial focus on teaching people primarily about the technologies that enable model creation to facilitating a variety of Activities—both on and off the computer—that help

Workshop participants learn to "think with models". In the spirit of Papert's technological samba schools (Papert, 1980), we aimed to create a Workshop environment where people would not only learn about *how* to model but would also collaborate as they explore how to learn things *through* modeling. Ultimately, we hope that teachers will be able to bring these ideas to bear in their own classrooms as well.

Our attempts to create a modeling culture that embraces both knowing how to model and knowing through modeling resulted in the inclusion of many Activities, like the Paper Catchers model described above. Participation in and reflection about models like Paper Catchers are just as important as the teachers' first experiences with StarLogo. Both kinds of modeling help people to explore patterns and processes in the world around them. The different models simply take advantage of different substrates for the model itself. In Paper Catchers, the model is "built" out of the people who participate. In a StarLogo project, the model is built in a computer program. Both models can be created, constructed, explored, and modified. We argue that participation in many kinds of modeling activities—both on and off the computer—helps people to develop a deep understanding of the types of problems that models can help one think about and the variety of models that one can construct.

This operational definition of a modeling culture draws heavily on our understanding of scientific culture and puts particular emphasis on the combination of the analysis and synthesis that characterizes scientific research through modeling (Hut & Sussman, 1987). Like the culture that it draws upon, our modeling culture is collaborative, creative, and centered around a community that possesses similar large-scale goals, though the foci of individual members of that community are unique. As in the world of science, our modeling community is less concerned with the use of particular tools, be they computer programs or white boards, that enable one to create and analyze models and more concerned with the kinds of issues that models can help to surface and explore—though facility with both the tools and the language of modeling is necessary to participate in such exploration. Our conception for the modeling culture also builds on our own practice, working with teachers and students to build fluency with new kinds of tools. We are interested in creating a community of practice among teachers, and ultimately their students, that utilizes models to think about domain-based problems.

Our Workshops, tools, and modeling curricula were created to enable novices to enter into a modeling culture. Participation in this culture can lead to the cultivation of fluency with modeling—the ability to use modeling tools to think through problems and create models of "significance" and the capacity to understand when the use of modeling tools is likely to be fruitful (Papert & Resnick, 1993; Resnick, 2001; Resnick, Rusk, & Cooke, 1999). Participation in a modeling culture can also lead to a clearer understanding of phenomena in the world, as people begin to generate, critique, and modify explanatory models.

Several components of our concept of a modeling culture informed our Workshop design, namely that members of the culture:

- Learn to express ideas through the creation of models.
- Discuss both the assumptions that define a model and the output that results.
- Help each other gain the technical skills necessary to build models.

- Develop the capability to think about models in different media.
- Collaboratively develop a set of analytical skills, which they can draw upon when investigating models.
- Use models to ask and answer questions about phenomena in the world around them.
- Understand what kinds of problems models might help them to think about.

We intentionally focused on the use of a variety of tools and the related ways of thinking with those tools. We are interested in influencing teachers to think in these new ways and curious to explore how these ways of thinking enter the classroom. Therefore, we are not concerned with adoption of the technology alone, but rather with adoption of the technological tools and the culture of scientific understanding that provides a context for their use.

This chapter describes the development of a modeling culture during the Adventures in Modeling Workshop. It surveys the kinds of activities that we feel are indicative of participation in this culture, paying special attention to the development of both teachers' modeling techniques and their epistemological understanding of modeling. The chapter also sets the stage for the three subsequent chapters. There we dive deeper into certain aspects of the modeling culture created during the Workshops. These include the role that multiple forms of media play, the process of forming a social context that supports research and development, and the ways in which the modeling culture formed during the Workshop exerts an influence on teachers' classroom practices.

Entering a Modeling Culture

In this section, we discuss the steps toward full participation in a modeling culture, namely developing the technical competence necessary to create and explore models, learning what kinds of models to build, defining an appropriate scope for a model, understanding how to critique models, and finally, developing an epistemology of modeling.

Developing Technical Competence

No prior technological understanding or specific skills are prerequisites for participating in Adventures in Modeling Workshops. Many teachers come to the Workshops with an interest in technology, and how it might apply to their teaching practice, but very little experience working with computers (see Chapter 3). Other teachers arrive with some computer experience, but virtually no one has any familiarity with designing, creating, or exploring models. Even those teachers who have experience with computers are initially uncomfortable creating their own programs. One Workshop participant explains his efforts on the first day to get the turtles to move backwards:

> Tony (a middle school science teacher from an urban charter school): This is my first experience with learning how to use a computer to program it to do something. Initially, after lunch—well, actually, before lunch, someone had mentioned that you could somehow make things go backwards, make the turtle go back, so I tried to do that. My first attempt didn't really work, but then we figured out how to make that happen. (Challenge 2 pinup)

Even though the back command, `bk`, is almost as simple as the forward command, `fd`, teachers need some time to develop a level of comfort with the technology. Right from the beginning, we encourage people to be playful as they explore the program. This playful stance is especially important for people who have limited knowledge, as they tend to panic if their technical skills are pushed too fast at the beginning. During Challenges 1 and 2, we provide plenty of time to explore StarLogo without relying on their ability to expand their command vocabulary. Teachers are able to take the first couple of Challenges to probe the boundaries of their knowledge, without any pressure. The kinds of things they explore differ, but many of them are quite basic. In this section, Tony describes his attempts to have a turtle draw a box and then retrace its steps. At first, he has trouble just getting the turtle to retrace its steps, due to the fact that the turtle is not oriented in the same direction after it draws the box. He shows the various buttons he built while attempting to trace over the box.

> Tony: We made a box, and then we wanted to just reverse that in a different color. The [button] to the right was what we thought would actually reverse it the first time. When you try that, you see that it doesn't; it has to do with the orientation of the turtle. The turtle's—when it completes the box, it's not facing the direction that initially we thought it would be. So we realized that the [button] on the left is the one that would actually retrace the box. I don't know what's going to happen. Try it again and see what happens. Okay.

Once he learned to anticipate the turtle's orientation he was able to redraw the box. He then realized, through playful exploration, that by changing a single variable he could draw and retraces shapes of any number of sides.

> Tony: Then, we started playing around with it, but different shapes. It works for—it doesn't matter what you set the angle at. You can make any shape just by changing the angle, you know, a six-sided shape or whatever, and then just hit the button on the left and it will reverse it. Then, we thought maybe we can use these buttons, and we realized that we were having a hard time exactly visualizing how these buttons redirect the turtle. So to get some practice, we wanted to try to actually see if we could trace a three-dimensional cube. That would give us practice really predicting which way it was going to go. We ended up having to make a whole series of new buttons. (Challenge 2 pinup)

Our experience in prior Workshops has taught us that many teachers, especially those who approach technology with some trepidation, want to be able to achieve results without spending a lot of time learning the details or memorizing a lot of commands. In other words, they need to get some results for their efforts right up front or they fall into a feedback loop in which their worst fears have been realized—they can't make the computer do anything and therefore they are even less likely to be able to relax and make the computer do what they want it to do.

We use a number of strategies to combat this problem:

- Teach the most leverageable commands first.
- Introduce commands through sample projects that can be modified and built upon.
- Create design Challenges that normalize knowing a small command set.
- Keep things fun and light-hearted.
- Combine off-the-computer Activities and computer models to provide multiple perspectives on modeling.

During the first few days of the Workshop, we lead participants in a number of Activities and design Challenges that get the members of the group on their way towards learning the technical aspects of modeling, without overwhelming anyone. The second Challenge, which they pinup at the close of the first day, simply asks people to add their own buttons and sliders to an existing StarLogo project.

Even so, for some teachers their first few steps are small and quite daunting. During the pinup for Challenge 2, teachers shared their initial experiences:

> Cathy (an elementary and middle school technology coordinator in an urban public school): One difference in our project, from the one we just saw, is that we didn't, for whatever reason, we didn't want it to keep drawing a circle over and over and over again, so we found that we had to play around with geometry a little bit so that it would make the exact number of turns and then stop once it had gone the full 360 degrees and drawn the entire shape. We also had some fun with elementary geometry, which we realized we were not as sharp with as we thought we were. [laughter]. (Challenge 2 pinup)

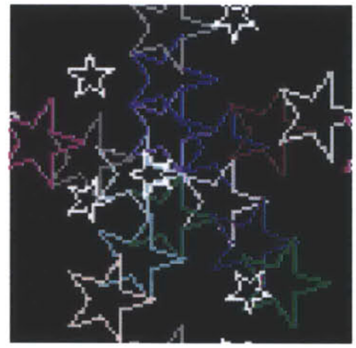


Figure 4: Cathy and Akira's funwithshapes project from Challenge 2.

There is quite a bit of nervousness for many teachers as they begin their first forays into modeling. While the interspersing of Activities helps to mitigate these feelings, they still surface during group discussions. For instance, teachers giggle about their difficulties with "elementary geometry", revealing their anxiety about any lack of knowledge, even when it has nothing to do with new technologies.

Though many of the Workshop participants have very little experience with technology, we wanted to stick to our goal of having participants learn how to build models without requiring direct instruction on programming. Yet, without any knowledge at all, it is difficult for teachers to build a model that does something and that situation can lead to a lot of frustration. The sample projects help a lot, especially at the beginning when many people simply modify them to get comfortable rather than attempting to build a new model from scratch. But even beyond the first few Challenges, we did not want to run a Workshop in which we were the experts, doling out useful commands and hints when we deemed it appropriate. Instead, we wanted to create a culture in which the teacher participants relied on each other and themselves for knowledge gathering. When teachers had questions or were stuck on something, we wanted them to go first to each other.

Of course, in the first few days of the Workshop, most teachers had very little knowledge about modeling in StarLogo, so creating a collegial atmosphere where peers could help each other was non-trivial. We used pinups to solve this problem. During the initial pinups, each group described one aspect of their project that they figured out and one that was still puzzling to them. As groups discovered important uses or unique applications for StarLogo commands, we prodded them to show pieces of their code and explain how it worked. In this forum, the rest of the group could both learn from their peers' successes and help them over the rough spots.

In the pinup for Challenge 2, Sandra, a middle school science teacher in a suburban public school, tells how she and her partner created a slider (which she calls a "slide bar") to choose colors in their project:

> Sandra: We went up to the paintbrush, and then we discovered, voila, that there are numbers on these colors. If you click on a number, you can then do the various shades of the number and pick out the one you want. Then, we made a slide bar so that we could do the number. Then, you don't have to click on the actual [colors].

Noah, a high school science teacher in a rural private school, was also using colors in his project, but had not created a slider to choose a particular color:

> Noah: We were messing around with colors too. How did you do that new color slide bar?

Sandra then leads him (and the rest of the audience) through the process of creating a slider. First, they created a new slider, then they named it "new color", and finally they gave it a range of color numbers. In this way, whenever they set the turtles to "new color", the turtles would assume the color that corresponded to the slider value.

> Sandra: We went up to—there's a dialog, see underneath Star Logo, the third icon is a slide bar. That's how we designed our slide bar.
>
> Noah: What did you do from there?
>
> Sandra: Slider six [It is the 6th slider in this project]. And then we did from zero to—it goes to 139. So we customized a slide bar that would go from 0 to 139.
>
> Noah: How did you tell it—how did it know to do color?
>
> George (a technology coordinator and administrator from an urban public school district): We defined [the slider] as "new color", and we gave it the range. Because in the book it said that you can have colors going in anywhere from 0 to 139. (Challenge 2 pinup)

In subsequent chapters we will talk more extensively about the specific ways that teachers learn from one another. The important things here are that teachers come in with very little knowledge, but even given that state of affairs, we do not want to lecture them about programming techniques. Instead, we have developed some strategies for making sure that they can learn from one another. The Challenges, associated sample projects, and pinups all provide a context for these early steps in building fluency with modeling tools.

```
to go
  ifelse race-over = false
     [fd 1 check-color go]  (1)
     [stop]                 (2)
end
```

Figure 5: Cathy's `go` procedure incorporates the `ifelse` command. If the race is not over, the turtles move forward and check-color (1). If the race is over, they stop (2).

In this example, Cathy answers Noah's questions about the `ifelse` command that she used in her project:

> Noah: What's `ifelse`?
>
> Cathy: You mean just like what does it do?

Noah: What does it mean? Yes.

Cathy: `ifelse` basically says I'm going to give you two conditions. I'm sorry. I'm going to give you two commands, and they are in brackets. Here's the first command, and here's the second command. Their condition is up here. `ifelse` 'race over' equals false. So if 'race over' is false, it's going to do this first [statement]. So if the race isn't over, it's going to keep going forward and checking the colors. Else, meaning if the 'race over' is not false, meaning the race is over, it's going to stop.

Noah: If the race is over, then you do what's in the second [bracket]. (Challenge 3 pinup)

The first step in building our modeling culture is bringing together people with very limited skills in the modeling domain, and enabling them to build knowledge and skills in a particular way—namely by relying on one another rather than listening to lectures from the facilitators. This choice helps to solidify the culture in the long run but sometimes makes the initial moments quite challenging.

Knowing What Kind of Model to Build

Part of becoming fluent within a modeling culture is not just mastering the technical issues of learning how to build models, but also mastering the conceptual issues of what kinds of problems models are useful for exploring. By the second day, when teachers have mastered a small set of commands and achieved a level of comfort in the environment, we introduce them to designing and creating their own models. This shift entails not only learning new commands and techniques (which have been present in the early Challenges) but also learning to decide on a topic that is suitable for modeling at their current levels of understanding and determining what kind of approach to use when building a model about that topic. When thinking about what kind of model to build, teachers move through several stages. In this section, we follow the evolution of their understandings. We see when and how teachers realize that modeling is not simply illustrating a process.

Before diving into the evolution of teachers' understandings, we delve into a brief description of three types of models, "illustrative" models, "analytical" models, and "simulation" models. Many teachers come to the Workshop with some conceptions about illustrative and analytical models. We use this typology of models to help teachers develop a deeper understanding of simulation models, since those kinds of models are best suited to enabling a fruitful modeling culture[9] and StarLogo was created primarily to allow teachers and students to create simulation models. The following explanation, which we discuss with the teachers, serves as a framework as they learn to make appropriate decisions about the models they will build.

What is a Scientific Model?

Most people have experience with models that illustrate scientific phenomena. Like the dioramas of elementary-school days, these "illustrative" models are meant to provide some kind of visualization of a scientific process or system. Models of this type include models of the solar system that show the planetary orbits, paper models of DNA chains that can be manipulated to

---

[9] One can also imagine a productive modeling culture focused on analytical modeling, but the members of that culture would need a far more extensive background in mathematics than either our participants or their students have.

show DNA replication or transcription, and transparent human bodies that show all of the internal organs. All of these examples are models because they illustrate an aspect of a scientific system or process—and help you understand it in new ways.

But a physics student would probably think very differently about the question, "What is a scientific model?" She might explain that $x = \frac{1}{2} at^2$ is model of how position depends on acceleration and time. An economics professor might discuss a model of supply and demand that is described by equations. These kinds of models, which are based on mathematical equations and enable exploration of a variety of scenarios, comprise a second category of scientific models—"analytical" models. Analytical models generate solutions that predict behaviors of systems based on a given set of conditions. For instance, using the equation $x = \frac{1}{2} at^2$ you can determine position (x) for any values of acceleration (a) and time (t). Many analytical models are concerned mainly with calculating an outcome rather than showing the process or dynamics of a system. While fewer people have direct experience with analytical models, they are critical in many types of activities such as forecasting economic cycles and predicting demographic trends.

In the past two decades, the growing presence of computers has ushered in a new approach to modeling. Many illustrative and analytical models can be constructed on computers, enabling people to study more complex problems than they could without the aid of computers. But computers also opened the door for another category of models, called "simulation" models, which would be difficult if not impossible to create without computers. In a simulation model, rather than solving equations, you describe the underlying mechanisms and let them "run" over time to see what happens. With simulation models, it is easier to incorporate random and probabilistic events, reflecting important aspects of the world around us. These properties of simulation models enable some explorations that are difficult to accomplish with analytical models (and impossible to show in illustrative models). Moreover, the flexible, intuitive nature of simulation models makes building them accessible to students of all levels. There are many kinds of simulation models, ranging from models that help people forecast weather to those that help people understand large-scale ecosystem effects.

Many phenomena can be represented by all three types of models. For example, if you wanted to build an illustrative model of the probability of getting all "heads" when flipping four coins, you could draw pictures of all of the possible outcomes of heads and tails with four coins. If you were building an analytical model of the same game, you could use equations to calculate the probability of getting heads four times in a row. In a simulation model, you could run a "four-coin" simulation and observe how often you got all heads. (And, in a simulation model, your results are not likely to be exactly the same every single time you run it.)

StarLogo is one platform for building simulation models. In StarLogo you build up complex behaviors from simple rules. The dynamic nature of StarLogo simulations allows for a kind of iterative exploration that you are unlikely to replicate in a classic illustrative model. And StarLogo enables you to define relationships among individuals in the system without using complex mathematical equations like those typically employed in analytical models.

A significant challenge in the Workshops is helping teachers move away from building illustrative models toward building simulation models.[10] Like many people, teachers tend to have much more familiarity with illustrative models. Their first few models often illustrate a process in the world that they already understand. As they enter into the modeling culture and their ideas of topics appropriate for modeling develop, they move towards creating simulation models. We have identified three modes of model building: pre-illustrative or "storytelling", illustrative, and simulation. The following projects document the different kinds of models that teachers build.

Telling Stories

Some teachers begin by creating a model that tells a story. Often, the stories progress in a linear fashion and do not incorporate much, if any, uncertainty. Though they occasionally capture an aspect of a system or process, they rarely enable the user to understand that system or process in a new way. For example, this project tells the story of children coming to a camp and learning to swim. Once the children take "swimming lessons" in the small pool, they are able to swim in the large pool. If they land in the large pool before their swimming lessons, they get sent to the hospital and then put on the bus to go home.

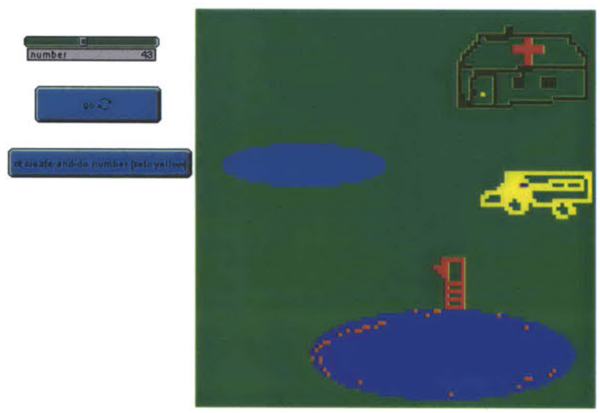


Figure 6: Bea and Gretchen's model, which they created for Challenge 4, tells the story of children learning to swim at camp.

> Bea (a middle school science teacher in a suburban public school): Our project is the summer camp scenario. Kids come in the bus, in summer camp, and then they run around places kind of at random, the way kids would. When they hit a smaller pool, a shallow pool, they get a swimming lesson, and then they turn a different color. And they go to the larger pool, and they can stay in there and swim. If they don't get the swimming lessons, and they go to the big pool, I wanted them to drown and die.
>
> Gretchen (an elementary school teacher at a Waldorf school on sabbatical): So, now I [will] do it very slowly. They go to the swimming lessons, here in the little lake. Those who can swim, they are allowed to go to the deep, dangerous lake. The others who go to the lake without swimming lessons, they have to go the hospital, immediately, they are sent by the lifeguards.
>
> Bea: See them popping up in the hospital?
>
> Gretchen: And then, after they are treated, they have to go to the bus. (Challenge 4 pinup)

Though the creators do talk about the process of learning to swim when they present their model, the model itself doesn't really illuminate much about the process—nor does it help a user to investigate possible patterns that one might observe at a camp (for instance, if a very popular child decided not to take lessons, how might that influence the other children). Even though the

[10] In all of the StarLogo Workshops that we have run, no teachers have built analytical models, probably because very few teachers have experience creating analytical models and StarLogo is an agent-based modeling system, which does not lend itself to creating analytical models.

women can get their turtles to move around the screen, their model is not a compelling one. No matter how many times it is run, the outcome is always identical, and the model does not illustrate any important aspect of the process of learning to swim. It does not make use of the affordances of illustrative or simulation modeling and does not provoke interesting explorations about the topic they are modeling.

Illustrating Topics

While storytelling models are relatively uncommon, and most teachers move past them very quickly, illustrative models are more typical. As they are developing early technical competence with StarLogo, many teachers build illustrative models, especially of phenomenon that they perceive as difficult to teach to their own students.

For Challenge 3, a team of three teachers created a classic illustrative model built in StarLogo. Their model demonstrates an electric current, by showing how some photons cause an electron to be emitted (see Figure 7) while others are just absorbed into a metal object. Each time the model is run, it sends out a randomly colored beam of light. Depending on the light's frequency (color), it will either be absorbed or reflected.

> Richard (a business person in the technology industry, transitioning to education as a second career): What we did was—Will is a physics teacher, and he came up with the idea of demonstrating photo-electronic—
>
> Will (a high school science teacher at a charter school): Photo-electric.
>
> Richard: Photo-electric effect, which—and the teacher [Will] is going to correct me here if I get this wrong, I'm sure—is the function where you shine light on a metal object, and only light within a certain bandwidth—
>
> Will: Correct.
>
> Richard: —will excite electrons to jump off of that metal object, creating an electron stream—
>
> Will: Right.
>
> Richard: —or what we commonly call a—
>
> Will: A current.
>
> Richard: A current. Electricity. So what we set about to do was to create, with Star Logo, a representation of that process. (Challenge 3 pinup)

When presenting this model in a pinup, the creators talk very openly about how the model aims to "demonstrate" or "represent" a scientific process. While the model does automatically send out light beams of varying frequencies, it doesn't allow the creators (or users) to explore what is happening or why and how changing the parameters might alter the outcome.

As an illustration, it is useful in that it does show the results for different frequencies of light, but it falls short of being a true simulation because it doesn't enable a user to explore different outcomes. The model's behavior (whether or not a light beam causes a current) has been pre-determined by its authors. Thus, the model animates a process without incorporating any of the features of the actual process. Instead, it simply shows it in a more dynamic medium than in a textbook.

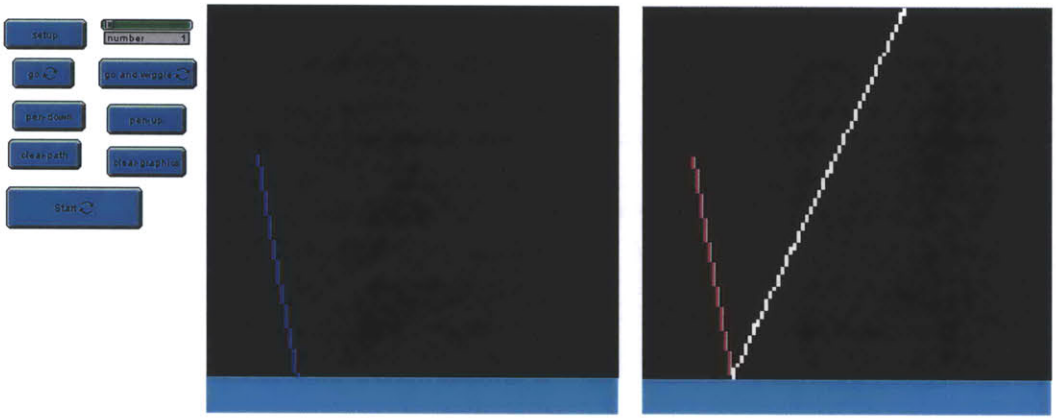


Figure 7: Will, Ivan, and Richard's model demonstrates an electric current. When light beams hit the screen they are either absorbed (as with the blue light on the left) or cause an electron to jump off (as with the magenta light on the right).

In Challenge 5, Will is still trying to build physics models. While not all physics models are illustrative in nature, and physics could be a good topic for building a simulation model, Will still approaches the modeling from an illustrative perspective. For this Challenge, he is trying to build a model of objects falling in a vacuum, in order to enable students to investigate why objects with different trajectories, when released, hit the ground at the same time. However, instead of creating a model in which balls move in the X direction based upon their initial horizontal velocity and in the Y direction based upon gravitational forces, he creates a model in which a ball is programmed to follow a path and increase its velocity in a fixed manner. This model illustrates objects falling in a vacuum. But the model is not a true simulation because the fixed description of the ball's path does not enable it to respond to gravity appropriately when its initial horizontal velocity is altered.

> Will: What George and I wanted to do, again, taking from my theme, which I just keep repeating, which is to do something from physics. They are all drawn on things from the classroom that I try and teach or show that [are] very difficult to do. This particular one is if you take a—this is in a vacuum—if you take a ball or take an object and drop it, and then you take another object and you throw it horizontally, they are both under the influence of gravity alone. They both fall in the vertical direction at the same rate and have the same vertical speed, and trying to demonstrate that in the classroom is virtually impossible. No matter what you do or say, the kids never believe you. So what we were trying to do was make simulation so that you take two objects, and you drop one object, and it falls. As it's falling, we have it changing color to show that it's speeding up. You can see how the color changes as it falls, and when it hits it has a certain color. Then, to have one shot off horizontally, and that one actually has to change its X and Y direction at the same time, so it has to do something like this. (Challenge 5 pinup)

There is nothing inherently wrong with building a model that illustrates a phenomenon. But these kinds of models do not take full advantage of the computational media and do not help teachers to explore the effects of different parameters or probabilistic events. When teachers build illustrative models, it is quite like coming up with a new analogy for a lecture on mitosis.

```
turtles-own [energy]

to go
   pd
   fd energy                       (2)
   wait .05
   setenergy energy + .125         (1)
   checkenergy
   if (pc-ahead = 15) [die]
   end

to checkenergy
   scale-color 45 energy 0 20
   if (energy > 65) [set energy 65]
end
```

Figure 8a-b: For Challenge 5, Will and George built a model of a ball bouncing. The ball did illustrate acceleration, by increasing its energy by 0.125 units every time step (1) and moving faster based on its energy (2), but those changes were not in response to gravitational forces in the environment.

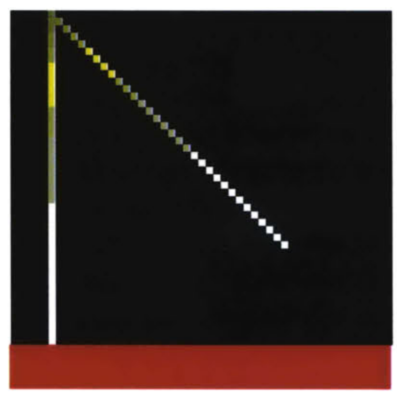


Figure 8c: A slight modification to the model shows that it illustrates acceleration but does not enable users to investigate why objects with different horizontal velocities accelerate vertically at the same rate.

There is nothing wrong with using analogies, in fact, they can help students to make connections to the material presented in the lecture. But enabling students to investigate a system and derive the rules of cell division could facilitate much deeper understandings. With respect to modeling, we feel that designing and creating simulation models gives teachers and their students the best opportunity to develop deep understandings of underlying mechanisms and the patterns and processes that they give rise to. To illustrate (no pun intended) why simulation models can be powerful learning tools, we turn now to the next model that Will created. This model is his first real simulation model.

Simulating Ideas

For Challenge 6, Ivan, a mathematics teacher at a suburban middle school, and Will built a model of investing. Though neither one of them was familiar with much economic theory, they used their model to explore the rules that they believed drove the exchange of information about investments. By creating a set of rules and a group of agents who interact in their environment, they built a small market and explored the patterns that emerged in their market. During this process, they began to compare their knowledge about markets in general with the behavior of their model.

> Ivan: The turtles are able to adapt. What they do is they gather information by colliding. There are different types of investments that are signified by the patch colors. And they set their headings based upon how much information they have. We put two sliders in. One slider controls the number of investors, and the other slider controls their ability to seek information. The more information they have, okay, determines what they're actually going to go towards. So if they have a lot of information, they're going towards the best investment.
>
> Will: They may start heading for one particular one, but then when they collide with somebody, the amount of information they have changes. Then they change their heading to point towards the block that has that information.
>
> Ivan: If you take 'ability to seek' and put it on 8 you end up with a lot in 'D'. If you manipulate the model and increase the number of investors, what you find is that you end up with a lot of A+ and A investments. That kind of illustrates, I think it's the rational market hypothesis. That shows that if you have a lot of investors and a lot of consumers that you actually—what's rational is that they seek out the best investment, so that's kind of neat.
>
> One last thing. Just increase that to, like, 99. Now, they're taking the same number of steps, but what the model shows is now that there's more interactions they are heading towards the better investments. (Challenge 6 pinup)

During the final pinup, Ivan and Will are able to explain their model in a fairly sophisticated way:

> Will: I'm a science teacher. Ivan is a math teacher. And this is more of an economics/finance project. So it's not something that we could use in our class. But it's something that we think could definitely be used in economics or a finance type class.
>
> Albert (a high school mathematics teacher in an urban public school): When the program starts, they sort of went out in a circle. Does that mean that initially they end up at an investment by luck?
>
> Ivan: No they have a random amount of information. It's like, life isn't fair, so some investors have more information initially than other investors. So they'll start out from the center. You can adjust the initial information level. At ten, it's a moderate level. But they start off from the center. And then they start encountering either other investors or other brokers. So their information level can change as they move out. So you can see, you can put at the model with a low number of investors; they tend to head toward the poor investments. With lots of investors they tend to head more towards the better investments because there's more interactions occurring. (Final pinup)

Will and Ivan created rules for their economics model based upon a few principles that they believed were major contributors to investor behavior. As they developed and refined their rules, they observed patterns in the investors' behaviors. Some of the patterns that emerged were aligned with Will and Ivan's expectations, while others were quite surprising to them. For instance, though they knew that increased information flow would likely lead to better investment choices, they were surprised that increasing the number of investors caused this pattern to occur. Upon reflection, they realized that more investors, in a fixed environment, meant more interactions between investors, and therefore more information exchange. Their simulation model enabled them to explore a dynamic system and investigate how the processes that they set up led to the emergence of patterns in their model.

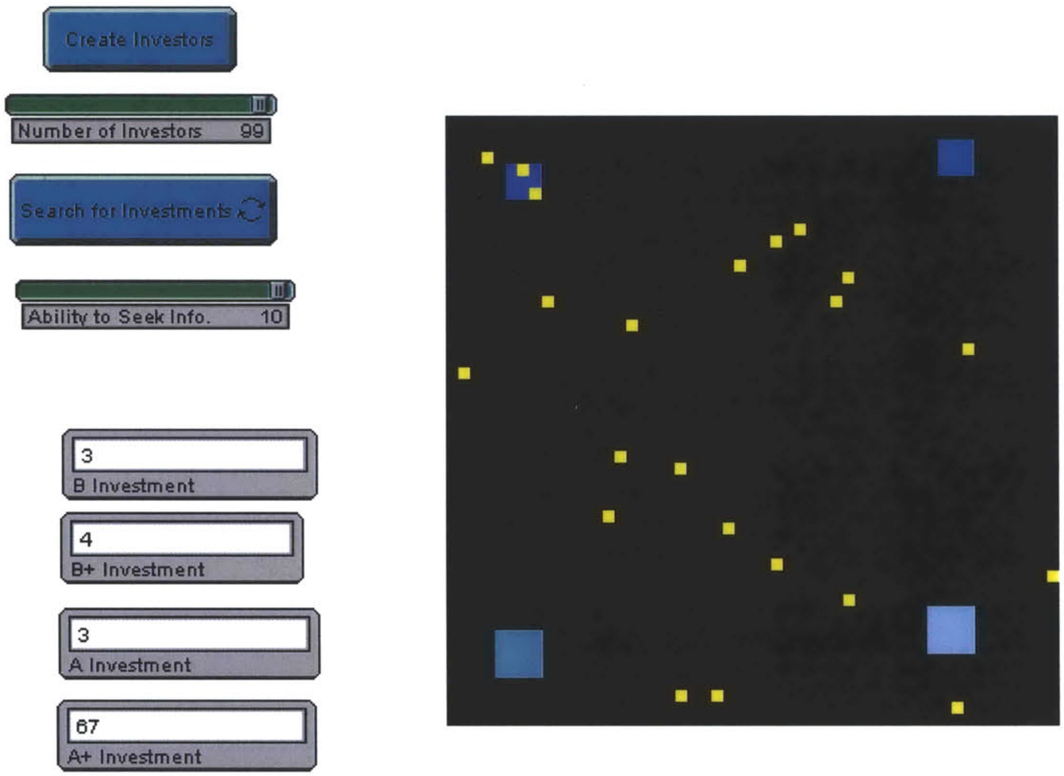


Figure 9: Will and Ivan's model simulates the process of investing. There are four possible investments, indicated by the four colored blue squares in the environment. The investors, yellow, move around the environment and exchange information about the investments. The more information they have, the better investment they will move towards.

From Storytelling to Simulations

Like the research scientists who build models to test their assumptions and articulate new ideas for colleagues, we want to engage teachers in a process of model design and creation that challenges their assumptions about phenomena and provides opportunities for investigation and reflection. As teachers move from building models that tell stories or illustrate processes to models that simulate systems, their stance towards questioning, experimenting, and developing better understandings changes as well. When they free themselves from the constraints of creating models that correctly show how things should work, they (paradoxically) situate themselves to build deeper understandings of how things do work.

Illustrative models are not worse than simulation models—they are simply different kinds of models. In the Adventures Project, we work hard to help teachers see the leverage that they can gain from using computational tools to enable them to explore questions that cannot be explored in other media. The collaborative nature of the modeling Workshops facilitate the exchange insights, like Will's, throughout the community.

Defining the Scope of a Simulation Model

An important aspect of developing fluency with modeling is knowing not just what kind of model to build but also at what level of specificity to build a model. As teachers delve deeply into creating simulation models, we find that many of them approach model building with the pre-disposition that "more is better". Their metric for a "good" model is one that comes as close as possible to simulating many aspects of the real world. As teachers work on projects, they are often uncertain about what to add to their models and unsure about how to pare down overly complex models.

We highlight another method of categorization to help teachers as they plan and construct their own models. This classification scheme, proposed by Roughgarden, differentiates models based on their purpose and the amount of real-world complexity that they incorporate (Roughgarden, Bergman, Shafir, & Taylor, 1996). Roughgarden defines three such categories of models—"minimal models for an idea," "minimal models for systems," and "systems models". We try to help teachers define the scope of their projects based on Roughgarden's taxonomy.

The first type of model, "minimal models for an idea" or "idea models," seeks to capture only the most fundamental parts of the system, without incorporating a high level of detail. Often, idea models are used to illustrate a general principle. The most useful idea models are those that strip away as much extraneous information as possible and boil things down to the most relevant parts. For example, one can create idea models of predator-prey relationships, supply and demand, and molecular motion.

The second type of model, "minimal models for a system," attempts to incorporate some aspects of an actual system without incorporating a fine level of detail about the system. A minimal model includes enough specificity to narrow the applicability of the model without including so much detail that it only applies to one particular case. These models represent generalized systems, like herbivores grazing on a grassy landscape or storeowners pricing baked goods.

The third type of model, "systems models," simulates an actual system with as much detail as possible. These models are usually built as a collaborative effort among many researchers, each gathering different details about a system and together synthesizing their findings into a huge model. Systems models require extensive data collection and intensive effort. A model of the growth, movement, and interactions of all of the plants and animals in Yellowstone National Park is a systems model. Models like this one often take years to build, even with the participation of many experts.

To clarify the differences among these model types, consider a model of population growth and how it might be modified to
could apply to any kind of living creature would be an idea model. If enough detail were added so that the model only applied to carnivorous animals, it would be a minimal model for a system. Finally, if a group of researchers collected and incorporated data on a single pack of wolves in Alaska, along with specific information about the prey that they hunt, the environment in which they live, and their relationships with one another, it would be a systems model.

Idea Models vs. System Models

Though many teachers begin with the notion that the more complex and realistic a model is, the better it is, StarLogo is best suited for the construction of idea models, like Will and Ivan's investment model. It is certainly possible to build a minimal systems model in StarLogo, but it is almost always preferable to begin by constructing an idea model and later expand upon that model if you feel it is useful. It is important, but tricky, for teachers to recognize that more detail does not result in a better model, it simply results in a different kind of model. As we move into the later Challenges, when teachers are beginning to build models that they can envision using in their classes, this problem typically crests.

Instead of focusing in on a particular idea or concept, teachers want to build complex models that they consider "realistic".

> Sylvester (a suburban science teacher in a suburban public school): We were trying to add to [our model] to make it more realistic. (Challenge 5 pinup)
>
> Noah: What we wanted to do was set up a situation where there would be a lot of variables. So this, the concept was to set up a situation for students where the students would have some variable that they could play with to get a result. (Challenge 3 pinup)

Throughout the Workshop, we encourage people to think about the aspects of the model that really interest them and remember that the complexity of a model grows exponentially as variables proliferate. During the pinups and desk-crits, we challenge groups to incorporate only those concepts that help them develop a clear understanding of the system, rather than trying to make models that are as complex and realistic as possible. Models that focus on a core set of ideas are often better learning tools, both for the builder and the user.

During the final pinup, several groups referred to our efforts to encourage them to focus on a key set of issues:

> Sandra: Eric was talking with us about our project. I said to him: 'We're thinking about doing a project on the rock cycle', but duh, how dull can you get. I mean that's so simple. He said: '[A] simple project seems all right. Take this project, ratchet it down a couple of notches and then you'll have your project.' How little did I know he was absolutely right. (Final pinup)
>
> Noah: And I wanted to do one of these glorious ecological things. But I couldn't program anything. And I was very frustrated and I had a great suggestion from the leaders of the project, that, you know, work on something simple. And, which is what I did. (Final pinup)

But focusing only on the simplicity of models misses an important facet of the issue. The point is that models, particularly the kind that teachers and students design and create, are not a replacement for the real world. Instead, these models are useful for exploring aspects of the real world. As mentioned earlier, there are more complex models that attempt to replicate systems well enough to predict things about the real world, but StarLogo is not an ideal environment for building and analyzing those models and they are far beyond the scope of what our modeling community is able to build or analyze.

We were excited that during this Workshop, teachers began to have high-level discussions about the realism that they felt was present, or should be present, in their models. Their viewpoints are a reflection of a fairly sophisticated understanding of the role that realism plays—and does not play—in learning through modeling.

How Real is Real Enough?

During the first week of the Workshop, teachers often expressed the viewpoint that their models weren't quite real enough. Frequently, they would present models during a pinup and show what they could do so far, but wish that they could work on them a little longer because 'then the functionality of the model would more closely resemble reality'.

In fact, some teachers never lost their enthusiasm for "real" models:

> Sylvester: The basic name of this project is The Unfinished Enchanted Forest. And what we tried to do is make this a little more visually real. And that's why it's unfinished because I think we went overboard on that... And the clouds are for all practical purposes set up so they will move to the right all the time, which is not realistic. But that's what we're stuck with right now. (Final pinup)

Sylvester feels strongly that the forest model would be improved if the clouds could move in more directions. In fact, it makes very little difference in the behavior of his model if the clouds move from right to left or left to right. The only substantive difference the feature would make is an aesthetic one.

As the Workshop progressed, most people began to appreciate the idea that getting "closer to reality" would not necessarily result in a better model. In fact teachers explained that sometimes, more realistic features were unnecessary for their models. Tony is describing an early version of his fishpond model when Sandra asks what would happen if his algae were immobile patches instead of mobile turtles:

> Sandra: If you have the plankton as patches, what would be your result?
>
> Tony: I'm actually working on, for my own project, basically this same idea, but using the algae as just patches. Really, the only reason I tried it that way is because I was hoping it would be a little bit easier. There's really no, other than for aesthetic purposes, there's no need to set the algae adrift. I mean, it's kind of more realistic that way, but in terms of the model itself, as long as the algae are reproducing and being placed randomly all over the screen, as they do, you don't really have to have them as turtles drifting around; it's not necessary. That's one of the really neat things about this whole program is that there's usually more than one way to accomplish a goal. (Challenge 5 pinup)

In the final pinup, many audience members from outside of the Workshop (other teachers and educational researchers) inquired about the level of realism in the models. We were especially impressed with the teachers' responses, because just as they had initially judged, more complex, more realistic models to be "better" so were many of their peers in the audience. Rather than become threatened or defensive, the teachers gave sophisticated, nuanced, honest answers about their choices of what they included in their models.

Ivan and Will both dabbled in the stock market and became interested in its behavior as a system. They built a simulation model (described above) to help them consider what kinds of information influence investment decisions. After presenting their model (which is quite abstract and not terribly realistic at all), they were asked:

> Audience member: Can you tell me a little bit about what you did maybe to sort of research the topic around the model or what insights you got from the model?
>
> Ivan: Well we really didn't research it. We wanted to make a model that incorporated information. And I guess the research was just through our own conversations about what the little investments we've made are like. And what we've considered in making an investment. (Final pinup)

When building idea models, teachers generally draw on their pre-existing knowledge about a topic of interest to them. Instead of requiring a vast amount of background research (which would be necessary for creating a systems model), idea models allow teachers to better articulate their existing understanding. Often, this process spurs them to further research and investigate aspects of the topic that they might not have previously understood. Their pattern of exploration is consistent with Dewey's notion that ideas lead to more directed observation, which in turn brings new facts to light and suggests fruitful directions to pursue (Dewey, 1938/1998).

Other teachers who built models with the intention of using them with other people gave more extended responses:

> Audience member: I know your time is limited here. But someone else asked the question. Were you able to see any studies, actual studies done in the environment in nature that would mirror this or did you get your data parameters from that or did you make all this up on your own?
>
> Cathy: Well this is something that we struggled with a lot when we were building the model. And what we wanted was to design something so that a stable system would see sort of classical oscillations in populations. So we tried to set the parameters, not based so much on research, but based on what will create a good representation of what might actually happen. So that's why right now, when you see most of the sliders in the middle, that's a pretty stable population. (Except for the speed, the speed one is a little sketchy right now.) But the idea is that when it's in the middle, you're seeing sort of classical oscillations. But then when you tinker with different things, you can compare and contrast. So it's not—for example, obviously fish don't reproduce three times and then die. It's a matter of tinkering with the model until you get something that seems representative of real life, was how we approached it. (Final pinup)

The recurrence of this type of question indicates the high level of resistance—even among educators and researchers who are already interested in learning through modeling—that many people have to the notion of using an idea model to think through pieces of a problem, rather than to replicate what happens in real life. In this case, Lawrence, a high school history teacher in a rural private school, built a model of the colonization of America in which students could build English and French merchant ships and naval ships. Rather than using the model to teach what actually happened in history, Lawrence wanted to use the model to get his students to consider (in a very stripped down environment) the kinds of decisions that need to be made when colonizing a new land:

> Audience member: Have you considered making a model that runs on its own—that does what colonies actually did?
>
> Lawrence: Well I don't think the colonies ran on their own though. And from time to time, there were pauses and you'd reflect and you'd make decisions. What I'm trying to do is get my students into that context, where they've got to stop and say, 'Oh man what are we going to do here? Things have changed a little bit. We're running at a net loss here, so how are we going to adjust what we're doing here in order to get back in the game here?' And so I want the kids from time to time to be able to make some decisions including what type of ships, what value of ships, where are those ships going to go.

Audience member: That was a really interesting response because there seems to be this trade off between the fidelity and the simulation in terms of recreating historical events and getting the students actively involved in that...

Lawrence: If I don't want students involved in the simulation, I'll just show them a movie. (Final pinup)

Again, the implicit suggestion that a more realistic model would be better resurfaces. Lawrence explains that he was not interested in building a realistic model—he was interested in allowing his students to directly explore a core set of issues that the colonies faced. Idea models that enable learners to engage with and investigate a piece of a problem, or that strip away extraneous facets of a very complex issue leaving a more approachable set of core issues, are often much better learning tools than highly complex models whose detail may obscure important issues.

The following extended excerpt from a reunion dinner in October illustrates how teachers thought about, and continued to grapple with, this issue well after the Workshop.

Julie (a middle school science teacher in a suburban public school): One thing I found—it's just such a short time that you're in the Workshop that a lot of the models that we're creating weren't really based on sound data. It was sort of like, if you're building a virus model and you assume that the virus increases two-fold every—that was the only thing. Somebody brought that up in the final session in the audience. One of the people said 'do you have those facts?' I thought that it's almost like, if you could have done some research before coming in. When you're in the throes of it, it's like, we were just proposing 'I think it'd go two-fold or three-fold' but we didn't really have time to hit the books or really research that. That would maybe be something you could propose—coming into it if you had thoughts on a certain area if you came in with some of the research done. I was just thinking—if this was something that was going to be sold by a company or marketed, you would want to do some research to make sure the numbers are right. If you had some ideas you wanted to work on you could research it and get the numbers and then it would be factual, not just kind of factual.

Bea: You want the model to be more real?

Tony: I heard through [Cathy], after the Workshop, that there was some discussion about whether the fishpond we worked on together, whether it was really representative of real life.

Julie: Well, the same guy asked this question of several people as they did their presentations. And... I think he even asked it of Lawrence—you know, the ships (Project,). He challenged, well not challenged, but he said 'Are you sure that is what exactly happened?' And he kind of said, 'Well, sort of.' I think that that was the only issue that was brought up was that some things were done off the top of our heads. And, it's like we teach it like we know it—you know, that kind of thing, but if you were selling it you would have to make sure the numbers actually worked right.

Tony: Yeah, if you were a scientist doing modeling, you would want to be using real data to explore whatever your questions were. But even in that case, I am very skeptical of models when you're trying to simulate reality. But, as a teaching tool I am much more supportive of models. Because, you could teach the water cycle from a textbook, and you have got a circle of arrows—you've got evaporation, precipitation, and condensation. But, you could also model the water cycle using StarLogo, and then it is direct experience. But it is not accurate. The water cycle is immensely more complex than a diagram shows or can suggest or anything that you could ever come up with in StarLogo. But that doesn't mean you can't use it to teach the fundamentals of what is going on.

Bea: I wonder if it really matters for the purpose we are using the models, with kids not being scientific researchers. I think it is even better that the model is less than perfect. Because kids can look at it and say, 'This doesn't seem right? Wouldn't those trees burn faster? Wouldn't this? Wouldn't that?' That is the kind of thing you want to encourage. If you present it as there is an absolutely perfect model of this situation that we researched and we got every single detail right and then you say, 'look at it and see what happens,' boom end of story. And I don't think we want that. I don't know; that's just my opinion.

Noah: When you design the model, the thing that happened in Workshop is that you had to be honest. We designed a model; it was about stress and lifestyle, survival and so forth. We realized when we were making the model that you could have the model come out any way you wanted. The model could show going to the health club once a week would increase your longevity and you could construct the model that way. If you wanted to show it makes no difference at all, you could construct the model that way. I guess I'm sort of in the middle—when you are doing the model, it is important to be honest, whether it is accurate or not.

Julie: I was meaning—there are times when I would have felt more comfortable if I was saying it happened at a two-fold rate than if I really knew it happened at a five-fold rate so that when I was presenting this as going along with the curriculum. Not that it would have to be researched up the kazoo, but just sometimes we were moving so fast to create models, like each day to turn out some sort of thing, that sometimes we would just speculate, 'Oh, I think this must be twice as much.'

There were times I was thinking if I was really going to use this tomorrow in class I would really feel more comfortable, if we were talking about the forest, that if you say certain types of wood would probably burn faster than others, or show different kinds of trees. At least if some of it was backed up at least you would be close to being correct, like soft pine burns faster than hard pine…

At least you're in the ballpark. Sometimes you want to make sure that you are at least something close to the original.

Male: Yes.

Sandra: Of course, if you push the slider at the other end of the spectrum—if you don't use any data, what you are doing is making the hypothetical. 'If we did this then perhaps this would happen.' What are you really gaining by doing that? I mean, it's all just possibility.

Max (a middle school computer and science teacher at a suburban private school): Not necessarily. Those numbers have to come from somewhere. And, you can push students to examine where their assumptions come from. Why do they choose to have the parameters range from two to 100 rather than 50 to a 1,000? To look at where their source of information are, what their deeply held beliefs are about some topic, whether it is forest fires or traffic patterns or whatever it is, and how that influences their thinking about the outcome. Whether they are surprised or comforted by the outcome of the model.

Again, it ties in with something I am obsessed about which is how people view authoritative information in the popular culture. You know, medical studies that are printed in the newspaper, things they are told and so forth. Because how people interact with that and use it in their everyday lives has a lot to do with their own belief systems, where they got their information, what they were told by their 7th grade teacher or whatever. So, I think it is an opportunity for us to do some reflective thinking. Where did you get the numbers to put into that slider? Why are those more valuable?

Noah: I have some experience on this. I used your model—Tony and Cathy's fishpond model—and we can find out from the modeler himself what actually was put into it. In this model they have some algae and some fish—some juvenile fish that grow for a while and become mature fish and the mature fish can eat the juvenile fish. Then they have this other slider with fertilization where when the fish die they fertilize the algae.

Anyway, the kids were playing with this and everybody around the room was playing with this thing and in the chapter that they had just read had nutrient cycle in ecosystems as a concept and ecological pyramids as another concept in the textbook. I went around the classroom and said, 'What is the ratio between the number of algae and the number of fish?' One group would find they had ten fish living and they had 1,000

> algae. Another group had 12 fish and 650 algae. They watched these numbers go up and down. And I would ask them, 'Does this remind you of anything that you read last night?' And they said it is related to the ecological pyramid.
>
> I guess what I am saying—because you could collect [data]—so that was all valid. The actual number was not valid but we said, 'Well, there it is and with the parameters that you used, how many offspring fish and so forth?' There would be this relationship between the consumers and the producers. Then when someone has different parameters, there would be different relationships between consumers and producers. That was extremely valuable because you could see dramatically that there were many possibilities in this ecosystem—there were many possibilities but they were all consistent with the ecological pyramid. They did not find three algae and five hundred fish.
>
> Then what happened that was really cool was then you put in the—you could move the fertilization and you could say, 'OK, now let's see what's happening with fertilization?' So, now you get the recycling of the resources—of the nutrients—and you find the change in ecological pyramids. I am not sure that that is exactly what happened, but I am sure that conceptually we really *discovered* something, that when you recycle nutrients that you get a more productive ecosystem. And that is a valid conclusion.
>
> In that way, whether the numbers were accurate or not, it was a very, very valuable teaching tool, especially when you get the kids talking about, 'What does your pyramid look like?' 'What does your pyramid look like?' They are all different but they are all consistent. And they saw the value of—the importance of recycling the nutrients in this model and they loved it. It was right there. You clicked on that fertilization—Vanessa made a slight modification of it—you click on fertilization, and visually—someone was talking about visual—visually you could just see the difference. You could see the change and you could look at the numbers and get some quantitative stuff and it was fantastic.
>
> It is sort of an example of—I guess what you would call drawing a conclusion and doing some experiments with models that are very, very real to the students. They are very real experiments. I think that the learning right then was very good—it was superb. It was a super kind of learning. (Reunion)

During this conversation, teachers not only exhibit a good understanding of how realism relates to modeling, they also exhibit a well-developed ability to articulate their beliefs about modeling. As they discuss the pros and cons of realistic models, their fluency with modeling is apparent. They can create, build, and use models. And they have developed the capability to reflect on how and when to use models for learning. In short, they have become full-fledged participants in a modeling culture.

Critiquing models

Of course, not every idea model is a good model. As in other communities, one of our aims in creating a modeling culture was to encourage people to constructively critique each other's work.

We found that during the Workshop people did get better at "self-evaluation" of models. They became better at judging their own models and seemed to be internalizing some kind of framework for thinking about the utility of different models. As Richard says in the final pinup:

> Richard: I think I also found confirmed the old computing adage of 'garbage in, garbage out.' I think you have to be really careful about sitting down to think out your model, and what the relationships are. And that it's based on good science and good concepts, before you go and set about programming it. Or you're going to have something that looks very nice but teaches the wrong things.

During the Workshop, people shared their insights about how they were developing these frameworks:

> Noah: One of the things that we found in this project and, probably because we had some time, was after we set up the physical model, was the setting of the variables so that the variables made some sense. What I realized, and what we realized, was that in setting the variables that you could affect the outcome of the simulation.
>
> There are two groups of people, and they are living in an environment, and in the environment there's a certain amount of stress that they interact with—those are the pink things. Then, we also set the—each one of those stressful interactions has a given intensity; so those are the things you can set. You can set the amount of stress, you can set the intensity of stress. Each one of the populations comes into this pattern with a certain genetic makeup. We realized that if you want to make the environment more important than the stress, then you set the environmental variables to a high level, but if you want to set the genetics more important than the stress, you set the genetic variables to the high level. When you run the simulation, you get a certain result. So I guess it's a word of caution to folks that when you do your simulation, you've got to make sure that when you start setting variables that either you have a purpose and you want to achieve that purpose, regardless of whether the relationship really true or not, or you want to check the data and make sure the variables correspond to reality, as best you know it. (Challenge 5 pinup)

But, we did not model, nor did the teachers become adept at, truly critiquing a poor model. I think there are two reasons for this, one more insidious than the other. The first is that a Workshop is a very short, and in some sense, fragile environment for creating a culture. People progress through the learning process at differing rates, and the very people who are building models that are "worse" than others are often the people who are struggling to keep up. In that situation, it can be almost impossible to criticize someone's best efforts. Also, because we don't criticize people's efforts right away, we do not build up the cultural discourse around critique that would be beneficial. Thus, Workshop participants don't have an opportunity to learn how to critique and how to take criticism.

Unfortunately, this rather understandable and explainable failing can be compounded by another more insidious problem—the grandmother problem. Recently, I watched a grandmother and her grandson. He was whacking away at a play piano (sounding terrible, as two-year olds often do) and she remarked that she read an article that one should not praise kids every time they do something if it isn't truly good. On the other hand, human instinct, especially when someone is just learning something new, is to overdo the praise in part as encouragement to keep trying. Just like grandparents who heap on praise because the young pianists are *trying*, not because they are actually good, a natural tendency when someone is just learning to model is to praise their efforts, even when those efforts are not stellar. The problem here is not that you shouldn't praise the first efforts (see learning in the previous paragraph)—the problem is when does it end. This syndrome can be a killer in educational technology because it leads to poor quality work being accepted (and apparently commended) and then it is difficult to make the case that these tools enable good, quality work.

Our Workshops have suffered from a lack of enough constructive criticism. While it is easy to attribute this situation to the brevity of the Workshop, it is critical to address the issue so that in a more extended community endeavor we are very careful to increase people's abilities to dispense and receive appropriate criticism.

As a brief example, the following model of a car race from Challenge 5 was not a good model. The underlying rules of the model were never well articulated and as a result, the model did not exhibit any of the behavior that Dick, a graduate student and part-time English teacher, describes here:

> Dick: One of the goals of this construct here was to create a setup where several variables would affect the outcome of one variable. Each one of these turtles is given a certain amount of energy. That energy is affected by variables called fuel and tires. As in racing, what happens is they choose a certain speed to go, and as they go forward, they wear down their tires, they wear down their fuel, but they are also trying to get the most laps first. But in racing, there's also a thing called a pit stop, where if you go to the pit stop, as you can see there, it goes up. So, in effect, what we're doing is we're creating an equation where fuel, speed and tires are interdependent upon the amount of time, the amount of speed used and the fuel consumed in that speed, as well as the tires consumed in the speed. So each time that you refuel, you have more energy, you have more tire wear on your car, and you can control the speed that you go at with sliders, which we didn't get to, and also increase the wait on your pit stop so that time can be factored along with fuel, tires and speed. So you would have four interdependent variables that you can adjust, through either setting your speed or taking a pit stop. (Challenge 5 pinup)

This model failed to capture any of the elements of the process that Dick described during the pinup. However, we did not effectively criticize it, in part because this group had really struggled just to get the cars moving. Dick and one of the other group members never built models that could be used to explore or investigate an idea. Instead, they built models that they described in complex terms but that did not exhibit anything but rudimentary functionality.

We hypothesize that a culture that more successfully incorporates criticism, by ensuring that it is seen as a constructive component of the community dialogue rather than as condemnation of a person's best efforts, will see more improvement in the types of models that teachers build, the explorations they conduct with their models, and the constructive criticism they can provide to other teachers and students—in short, such a culture would improve the learning process.

Developing an Epistemology of Modeling

Our Workshops teach people how to build models in StarLogo. They help teachers develop the capability to discern the difference between illustrations and simulations and the ability to distinguish an idea model from a systems model. But the central reason that we try to create a modeling culture is to help people develop a sense of why to use models and an appreciation for how modeling is another way of knowing. A model might help someone explore a new topic or gain a better understanding of an observed phenomenon. Or it might enable a person to show someone an instantiation of an idea or display data from a particular investigation. All of these (and many others) are valid reasons to build models. Ultimately, we want the teachers in our Workshops to come away with an understanding of why modeling can be a good approach to gaining or developing new understandings. Then, irrespective of whether or not they choose to use the Adventures Activities and Challenges, we will have broadened their understanding of how to understand the world around them.

In the first few Workshops, our focus was tightly centered on teaching people to design and build models in StarLogo. We used many of the same mechanisms, including Challenges, pinups, and Activities, largely to reinforce people's understandings of how to *create* models. This past summer, we embraced the notion that we should focus broadly on developing people's understanding of model creation, supporting their investigations of different kinds of models (from StarLogo-based models to "people-based" models), and developing their conceptions of how to use models for exploring ideas. Now that we have expanded our focus, we have seen teachers develop much deeper appreciations of the strengths and limitations of modeling as a way of building knowledge.

The teachers in our Workshops are interested in both their own learning processes and in how their students will be able to use modeling as a way of learning and knowing. After the Workshop, Tony and Cathy discussed how they envisioned using models as a way of teaching. Their conversation reflects the earlier debate about realism in models, and also shows a sensibility about how those issues come to bear when using models for teaching and learning. Here are a few excerpts from their email conversations:

> Hi Cathy, I hope the last two days of the StarLogo Workshop went well for you. You must be getting ready for the new school year... I finally sat down and looked at our fishpond project... I'd like to chat with you about how we can use the model to teach about ecological relationships, and make improvements to the existing program. I think there are really a lot of possibilities. Tony (8/23/00 email communication)
>
> Hi Tony, Good to hear from you, and I'm sorry I never e-mailed you to let you know how the final presentation went... The one question from the audience that I really remember pertained to how closely the behavior of our fishpond is like a real fishpond. There were several audience members who were very concerned with the relationships in the simulations being exactly like relationships in real life, which to me doesn't seem very fruitful. But anyway, it does raise some interesting questions about how to put the simulation in context for students (i.e., this isn't a REAL fishpond, but what can we learn from it anyway? What are its limitations?) Cathy (8/24/00 email communication)
>
> Hi Cathy, I agree with the critics of our fishpond simulation... The fishpond model does not mimic reality. However, like a schematic diagram, the model does convey certain key concepts, which do reflect ecosystem processes. For example, if the algal population in our model is allowed to grow unchecked, the population numbers will increase exponentially. In real life, no population can grow forever because resource consumption must have limits. We could make our model more accurate if the algal population were to crash at some large threshold number. Furthermore, the unstable, fluctuating pattern observed in the algal population when we introduce a population of fish is similar to that which is observed in predator-prey relationships in nature. I hope this convinces you, and others, that the fishpond model is a useful teaching tool.
>
> Similarly, a schematic diagram of the water cycle helps learners to understand the fundamental aspects of what is in reality an extremely complex system of interaction. When we teach about the water cycle, we do in fact oversimplify what is really going on. I could fill a book with useful, yet highly oversimplified, graphic models of complex systems. Fortunately I don't have to, just look in any college level biology, physics, or chemistry textbook. They are packed with oversimplified depictions of complex systems. Yet nobody denies that they are useful teaching tools. We could not communicate if we did not simplify things. Tony (8/24/00 email communication)
>
> Hi Cathy, I have been thinking about my suggestions from last month on how to make the fish pond model more realistic. I still think these suggestions are pretty good, but far from perfect. I feel it is important to debate the limitations that go along with attempting to create a simple model of what is in reality a far more complex, highly variable system. Tony (12/29/00 email communication)

During their correspondence, Tony compares StarLogo models to "schematic diagrams" in textbook, noting that while they are simplifications of reality they are good teaching tools because they enable students to focus on certain "fundamental aspects" of the system. The Workshop participants use models to build their own understandings and develop theories about how models can be effective teaching tools. They begin to appreciate how models can be used for exploring, investigating, testing, and challenging ideas—in short, they understand how modeling is another approach to gaining and developing new understandings.

5. Combining Media

The Flight of the Humanboids

One afternoon, a few days into the Workshop, the group headed out to the great lawn. The teachers were told that they were all going to pretend to "be birds" and "come up with some flocking rules that allowed [them] to flock around the field and stay in some kind of formation. Rather than each following [their] own individual flocking rules, [they] were all going to have to agree on a set of flocking rules that would allow [them] to keep in a cohesive flock."[11] Before taking off, the teachers proposed a set of rules, which they believed, when followed by all birds, would result in the formation of a flock:

> Cathy: Have one hand on like the closest shoulder of a person that's in front of you.
>
> Bea: How about conditions, you know… If you could change directions, but not if you are in the middle, only if you are on the edge.
>
> Albert: I say we just get within one foot of the person who is closest to you. [And] move if you feel like it.
>
> Cathy: Don't pass the person in front of you.
>
> Dick: Say yup whenever you move. Yup. Yup. Yup.
>
> Noah: If you move, move in the direction of the person in front of you, and if there's nobody in front of you, then you have the freedom to move wherever you want.
>
> Lawrence: What I thought was, we have to first step as a flock. So, people should be allowed to wander somewhat randomly to establish it. But, maybe the rule is, once you are in the flock, which is—you manifest that by having your hand on someone's shoulder—then whenever you are in that formation, you have to face—you have to orient together.

Figure 10: The teachers' first attempt at flock formation.

Once they agreed on a set of rules, they took off and "flew" around the lawn. Silent, except for a cacophony of "yupping", they made their way past tour groups and Frisbee players. After a few minutes of attempted flocking, they reconvened to critique their original set of rules. During their discussion, they tried to predict if and how their flocking rules might allow the Humanboids to avoid obstacles, like trees and predators.

[11] The facilitator's instructions at the onset of the Flight of the Humanboids Activity.

Noah: I was going to say that [our flock] is much too confining. It's two-dimensional, so we need—I'd say, we need to not touch.

Cathy: So, follow but don't touch.

Sandra: Maintain a one-foot distance from the nearest bird.

Richard: Maybe that's how you change direction is… If you always maintain a certain distance from the others who are around you, [then] if there's a change in direction, in order to maintain that distance, you have to move in that direction. So whoever is out in front, when we come to the tree, if they move in a direction to go around the tree, then you move with them.

Sandra: We still haven't established how to be a flock yet. Once you introduce a predator, the flock disperses in a thousand directions.

Dick: Or they gather, for example, a school of a lot of small fish will gather into a school in order to make a larger fish think it's a bigger fish.

Once they settled on a refined set of rules, which also allow for predator and obstacle avoidance, they took off and flew around the lawn again. This time, their "yupping" took on a new tone and began to sound almost like communication. As predators approached, the Humanboids who first saw the predators began to "yup" in a high-pitched tone. This warning quickly propagated through the flock. Yet, even in the face of danger, the flocking rules weren't quite sufficient for all of the Humanboids to reach a safe haven. After the Activity, the teachers compared their flock to their previous knowledge and intuitions about bird flocking behavior:

Dick (a predator): I think flocking behavior is a by-product of survival is how I saw it. The people that stayed in the middle were safer. The people on the outside—the people in the front were more likely to bolt than the people in the middle.

Lisa: If you were on the outside, you felt vulnerable.

Noah (a predator): I noticed that what we didn't do is, compared to what you see like on the nature shows, I think that it would be like, when that stalling happened, that would sort of be a message for turning, and you guys didn't do that, you sort of just stalled. When the lion gets in front of the wildebeest herd, then they all turn. So that could be like, when the distance shrinks, turn.

Cathy: When you are in [the middle of the flock], you rely on the people outside to make a move first, because you can't direct any turning motion from within the group. You just kind of have to wait. It's almost like the person on the opposite side of the flock has to initiate the move. It's like if the predator is coming from the right, the people on the left have to move away, because obviously the people on the right start moving toward it. Do you know what I mean? It would be more efficient if the people on the far side could move away, but they are not the ones with the information, so somehow—

Richard: Yes, it strikes me birds and animals have some kind of rule that we haven't figured out yet.

Figure 11: The flock tried to avoid the two predators as they approached from the left.

Humanboids is a model of birds flocking. Just as StarLogo models exhibit observable behaviors when they are run, the Humanboids model also exhibits behavior when the model is "run". Like behavior in a StarLogo model, the Humanboids model's behavior is based on a set of underlying rules, and those rules produce recognizable patterns (i.e., a line in their first attempt and a flock in their subsequent attempts). In between flocking attempts, the teachers tweaked their flocking rules. They were able to see the resulting effects on the system when they run the model again.

Humanboids is an opportunity for teachers to experience and reflect on a decentralized, emergent system. Systems like this one, which have no leader but instead exhibit patterns that emerge from the interactions among individuals, are quite common in the world but are very difficult for many people to understand as they go against people's intuitions about the behavior of systems (Resnick, 1994).

> Bea: Doesn't it seem like, we said no leader, but they way we are talking, it seems like we are looking for a leader here.
>
> Sandra: Are we considering the edge of the flock the front edge and the back edge? In other words, the person at the front of the line and the person end of the line? So, how do you know—if one of those people moves, then everybody follows, but if they both move [then what do you do]? I mean, to me, you've gotten—you can't have a leaderless flock.

Modeling (both people-based and StarLogo based) is an opportunity for teachers to illuminate their current understandings and explore new ideas. Though some people are quite comfortable questioning their own assumptions, others are less inclined to pursue such questioning. Humanboids is just one of many instances during the Workshop when we try to challenge people's intuitions and assumptions about the behavior of complex systems. By involving people directly in the simulation, we use their own experience to provoke them to compare their intuitions and understandings to the patterns and processes they create and observe.

Many of these tasks, from thinking about underlying rules to questioning long-held beliefs and intuitions, are difficult for people. We rely on Activities like Humanboids to involve teachers with different styles of learning and to provide multiple perspectives on the issue for all participants. We find that insights spring up from many different contexts, perhaps because people require a variety of experiences to achieve the level of comfort that is sufficient for them to explore their own understandings. For some teachers, methodically building a StarLogo model helps them to develop a deep appreciation for systemic behavior; for others, StarLogo is initially intimidating but flocking around the yard is accessible, while for others the combination of both experiences helps them develop a deep understanding. In the Workshops, we place no value judgment on which approach is "better". Instead, we aim to provide a diverse set of experiences that support teachers' developing understandings. It this chapter, we discuss the ways that off-computer Activities provide one pathway to participation in a modeling culture.

Modeling in Multiple Media

Like other models, StarLogo models can serve as tools that help people to make sense of the world in a different way. After playing with a predator-prey model in StarLogo, a student might have a different understanding of the relationship between the deer population and the shrub population in her backyard. After designing and creating a model of genetic inheritance, a teacher might develop a clearer way to think about the molecular interactions that lead to patterns of genetic inheritance. Yet, in order to achieve this use of a StarLogo model as a "lens" through which one can view the world a little differently, one must be able to construct connections between the model and the patterns and processes in the world that it represents. Through activities, people are able to make personal connections to the science content (Lehrer & Romberg, 1996; Resnick & Wilensky, 1998), and engage in reasoning that bridges intuitive and scientific knowledge (Lehrer, Horvath, & Schauble, 1994).

The idea to use direct, personal participation to help people gain new perspectives or build better understandings is not a new one. Dewey emphasized the value of personal participation in educative experiences throughout the curriculum (Dewey, 1988). Researchers have attempted to connect personal and physical interactions to underlying systemic mechanisms in a variety of ways. Papert (1980) tried to forge links between human action and the rules of Turtle Geometry by asking children to pretend they were the turtle and then translate that understanding into a symbolic representation of the instructions for the turtle's movement. Resnick and Wilensky (1998) expanded upon this idea, involving large groups of people in activities to help them gain a richer understanding of the rules governing emergent systems. Recently, Wilensky and Stroup (1999) developed a network architecture that gives students control over individual agents in a simulation environment. Researchers in systems dynamics also use group activities to help learners develop systems thinking capabilities (Booth Sweeney & Meadows, 1995, 1996; Meadows, 1986; Senge, Roberts, Ross, Smith, & Kleiner, 1994). Others use wearable computers to create an explicit link between personal experience and underlying computational rules that mediate those experiences (Colella, 1998; Colella, 1999; Colella, 2000; Colella, in press; Colella, Borovoy, & Resnick, 1998a; Colella, Borovoy, & Resnick, 1998b).

The richness of learning through experience occurs not just during the activity (Brehmer, 1980) but as participants are able to step back from their immediate experience and analyze the situation. Ackermann (1996) has described this process as *diving-in* and *stepping-out*, as people move back and forth between full immersion *in* a problem and thinking *about* a problem. Similarly, Sterman (1994) distinguishes between the features of learning *in* and *about* dynamic systems (see also (diSessa, 1986)). Many scientific problems offer the chance to step outside of the problem and think clearly about it. Relatively few offer the chance to dive convincingly *into* a problem. The Adventures Activities create opportunities for participants to enjoy both of these important perspectives during the processes of defining and solving problems.

The notion of diving *into* a scientific problem in order to better understand it has not always been highly valued by researchers. The scientific community has traditionally valued detached, objective modes of experimentation, at the expense of more "connected" methods; however, some examples from scientific practice indicate that a revaluation of connected science may be in order. Keller (1983) describes how diving *into* a problem helped Barbara McClintock yield innovative and previously unimagined solutions to scientific questions. Other researchers have explored the notion of "connected" mathematics and science in education (Wilensky, 1993; Wilensky, in press). Building new, well-integrated scientific understanding rarely comes from a single perspective (diSessa, 1988; Turkle & Papert, 1992). It is the combination of experiencing Activities and reflecting on them, and approaching problems from multiple perspectives (both computer-based and off the computer), that enables people to build deep understandings.

Fostering the ability to connect personal experience with a complex, dynamic system and experience with modeling a similar system can also enable people to engage productively in analogical reasoning about the system. Making these kinds of connections between experiences (or other related systems) and a new system under study is not simply a technique for novices. Researchers use both local (closely related) and distant analogies when they are trying to develop new theories or explain phenomena to colleagues. In fact, the use of these analogies is part of what drives the discovery process (Dunbar, 1995). During Activities, participants use analogies that resemble the local analogies that scientists use when trying to develop explanations with their colleagues.

Many people think of multi-media as flashy computer programs that combine visual effects, sound, and interactivity. We have pursued a different, and we hope ultimately richer, sense of multi-media. The Adventures curriculum combines on-screen computer modeling with "in-the-world" Activities and Participatory Simulations to provide a diverse set of modeling experiences.

Activities

Like computer models, the Activities that we developed for the Adventures in Modeling book and Workshops offer a way for learners to collaboratively investigate the relationship between patterns and processes in the world and the rules that give rise to those patterns and processes. The Activities share key characteristics with computer models (which can be repeatedly run, analyzed under different conditions, and modified and further explored) and deploy them in the context of a real world experience. They enable people's direct participation in simulations of complex, dynamic systems in real space. Participants' personal connections to the Activities encourage them to bring their previous experiences to bear, help them to rely on analogical reasoning, and lead them to establish strong connections to the Activity, to other participants, and to related models. The Activities are important both as teachers are first learning about modeling and as they begin to integrate modeling ideas into their own courses.

We have developed the following Activities for use in the StarLogo Workshops:

- *A Round of Applause* enables participants to experience and reflect on how and why emergent patterns are generated and how changing the flow of information alters that pattern formation.
- *27 Blind Mice* from lets participants explore the differences between and the consequences of global communication, where every group member has access to information, and local communication, where information exchange is limited to personal communication channels (adapted from (Resnick & Wilensky, 1998)).
- *Pixelated Paths* introduces participants to building sets of instructions for turtle/environment interactions.
- *Watch Your Investments Grow* engages participants in a rule-based model of a growing population.
- *Survival of the Fittest Paper Catchers* puts participants "inside" of a growing population (described in Chapter 4).
- *Sold! to the Highest Bidder* allows participants to explore how simple rules—and interactions among those rules—can sometimes yield unexpected results.

- *Foraging Frenzy* immerses participants in a fight for food that causes them to making decisions about food gathering and enables them to experience a model of optimization.
- *Majority Rules* allows participants to experience the dynamics of, and reflect on the mechanisms of, opinion adoption.
- *Flight of the Humanboids* challenges participants to generate coordinated behaviors by relying not on centralized control but instead on simple rules (described in Chapters 3 and 5).
- *The Gambler's Dilemma* engages participants in a spirited exploration of the balance between optimal individual strategies and successful group strategies.

Complete descriptions of all of the Adventures Activities can be found in the Adventures book (Colella et al., 2001).

Participatory Simulations

While many of the Adventures Activities employ materials that are quite familiar to teachers, a few of our Activities do not. Participatory Simulations use small, wearable computers to involve teachers in simulations that are mediated, in part, by technology (Colella, 1998; Colella et al., 1998a; Colella et al., 1998b). Each participant wears a small computer, called a Thinking Tag (Borovoy et al., 1996), that executes rules and keeps track of important information during the simulation. The simulation results from the interactions between the rules that are programmed into the computers and the behaviors that people adopt. For instance, during the pond ecology simulation some participants become schools of "big fish" and others become schools of "little fish" by wearing Thinking Tags that display the number of fish in their school. As they interact with one another, the big fish "eat" little fish and the little fish "eat" fish food. The Tags calculate how many little fish a big fish can eat and keep track of the number of fish in each school. These Activities build on the characteristics of microworlds, in which computer models can be executed, and augment them with the affordances of real world experience, enabling learners to become the participants in computer-supported simulations of dynamic systems in real space.

As in a non-technological Activity, learners can experience and influence these simulations directly. For example, during the pond ecology game, participants can alter their behaviors and change their strategies. Afterwards, they collaboratively investigate the ways in which cooperative and competitive behaviors alter the dynamics of the ecological system and change the carrying capacity of the pond. In another Participatory Simulation called the virus game, participants interact as a disease moves through their community. Then, they work to analyze the disease dynamics and establish how the behavior of individuals influences the outcome of the simulation. In all of these Participatory Simulations, people collaboratively explore the system by changing their own behavior, collecting data, running experiments, and observing the effect that their behavior has on the dynamics of the system.

We have developed the following Participatory Simulations:

- *The Virus Game* challenges participants to stay healthy as an initially invisible virus invades their community.

- *Big Fish Little Fish* immerses participants in the fight for survival, as little fish scavenge for food and big fish attack little fish, and provokes an examination of the roles of collaboration and competition in systems.
- *Tit for Tat* allows participants to investigate how cooperation can evolve in communities over time.

For extended descriptions of teaching and learning with Participatory Simulations, see Colella (1998; 2000; in press).

Combining Experiences at the Workshop

Both the Adventures Activities and the Participatory Simulations are integral components of the Workshop's pedagogical structure. In this chapter, we explore how and why the Activities, when used in concert with modeling Challenges, facilitate the development of a modeling culture. Specifically, we describe how these off-computer experiences:

- motivate teachers,
- illustrate the importance of appealing to multiple learning styles,
- encourage teachers to build connections between their experiences and modeling,
- highlight the notion that modeling is a "lens" through which one can view the world, and
- validate existing teacher practices.

Motivation

Many experienced teachers recognize that involving their students is one key to facilitating good learning experiences. In the Adventures Activities, teachers can really dive into the experience. This intense level of involvement both helps teachers to learn new ideas, and, in a fashion similar to what happens for younger students, it helps them shed their "teacher" identities and participate fully as learners.

> Cathy: Going back to Vanessa's original question about the Activities. As far as being able to see what you have an impact on—even the things like the hand raising or the hand squeezing—[help you be] able to get a feel for what the relationship is between the part and the whole. I think, you know, especially for kids. I mean, for adults, too. I found it really helpful as far as piecing together and just thinking about how the turtles interact, how the turtles perceive the world, and then put us in a position where all we can perceive what is immediately around us. I think that's a really helpful connection, and I think to make it concrete like that really does foster the kind of thinking skills that you're talking about. (Workshop discussion)

Initially, Cathy is commenting on how useful the Activities are for helping students develop a deep understanding of the relationship between the part and the whole, but mid-sentence she reflects on the fact that they have also been very helpful for her as a learner.

Participatory Simulations are another exciting way to get teachers (and their students) involved in the scientific process. One of our teachers described how the students and teachers back at his school reacted to the virus game:

> Carl: The kids were enormously enthusiastic, and we heard from parents the next day about how excited the kids were about it. The science teachers in the middle school were enormously enthusiastic too. (Reunion)

Of course, motivation is really only the first step toward a rich learning experience. We turn now to other aspects of the learning process that are supported by the Activities. In Chapter 7, we explore how Carl capitalized on this motivation to involve teachers at his school in more modeling activities.

Supporting Multiple Learning Styles

In the past decade, the notion of multiple learning styles has become popular (Gardner, 1983; Gardner, 1991). It is now the prevailing view that people learn in different ways—and that there are different, equally valid, ways of understanding the world. Our combination of computer models and Activities is designed to appeal to multiple learning styles. Teachers recognize the importance of this approach:

> Liz (a middle school mathematics and science teacher in a rural public school): I also like the Activities because they take the—they take you away from the computer. And, you know, it's—and everybody learns differently and if you have a classroom full of kids then some of them don't like sitting in front of that computer, and others love sitting in front of the computer. You get more learning styles and you are modeling something in a different field and it's good and teaching sixth grade they love to work on it. (Workshop discussion)

Just as it is valuable for students, it is valuable for teachers to have the opportunity to learn in different ways.

Learning in different ways is not only important because every learner approaches a problem from his or her own unique perspective. It is also essential because learning the same thing in a different way increases the chances that deep understanding will result. Or to paraphrase Minsky, 'you don't really understand something until you have understood it in two ways' (Minsky, 1985).

Building Connections between Experience, Activities, and Models

Seeing the World Anew

Activities are not only important because they are off of the computer screen. They are important because they occupy a space that is both a part of personal experience and an enactment of an external process. In other words, because an Activity is structured as a simulation of a system, in some sense it is both an experience that people have/encounter and a model, which can be explored and reflected upon. This property as an "intermediary system" is helpful both as people begin to view their own experience of the world in a different light and as people begin to draw upon their experiences when designing and creating computer models.

Here we see how an Activity helps teachers begin to understand patterns and processes in the world a little differently. The day after a rousing game of the Flight of the Humanboids, described above, Noah and Lawrence shared an experience with the group.

> Noah: I'll just mention that, yesterday, after we left, Lawrence and I observed flocking behavior in humans. It happens when a group of people [is] in a conversation, and they are walking. It was really cool

> to watch because there's a whole bunch of unwritten rules. You see all this, you'll see people walking, and they'll change places, and they'll avoid obstacles. And, the motivator is—
>
> Lawrence: To stay within a conversational earshot.
>
> Noah: —is to remain in a conversation. It's really cool. I mean, it's fluid, and it does all of these things that a flock is supposed to do. (Challenge 4 pinup)

Their experience in Humanboids "primed" Noah and Lawrence to be looking for patterns or processes in the world that, like the flocking in the Activity, might exhibit system-level behavior that is based on an underlying set of rules. Humanboids gave them an experience of a complex, dynamic system, which was useful in and of itself and as a tool for thinking about other instantiations of similar systems. Through their experiences in the Workshop, they began to see systems in the real world through "modeling lenses", looking for rules that allow behavior to emerge or finding clues as to how the underlying structure relates to the observable behavior.

Activities help people to build connections between patterns and processes in the world and the more abstract or simplified or conceptual instantiations of those same patterns and processes in models. They help people connect their experiences (either in the Activity or in their own lives) to the model and begin to see models on top of real world phenomena.

Our goal is to enable people to think about modeling as tool that is connected to their own experience, not just a new thing to do with computers. Through the Activities, we aim to help participants develop a broad conception of modeling that embraces modeling in a wide variety of media, from cutting edge technologies to pennies and strings. The Activities are quite abstract on their own, when you consider the simplification that occurs when translating real bird flocking to people following flocking rules, yet by making this abstraction concrete in the form of an experience, they help people to make connections to the abstracted model. It is this kind of thought process, more than simply programming computer simulations, that is at the heart of the Adventures in Modeling Project. We find that participation in Activities is one path towards developing an understanding of the utility of modeling.

Drawing on Experience During Model Design and Creation

The Adventures in Modeling Workshops aim to enable people not only to view aspects of the world through "modeling lenses" but also to create their own models—for it is the interplay between observation, design, creation, and investigation that allows people to deeply explore how they understand systems. In this section, we are especially interested in how the Activities facilitate the process of model design and creation. First, we look at how participation in Activities encourages teachers to put themselves "inside" the model as they imagine what they will build. Then, we discuss how teachers draw directly on the Activities for ideas about what to model. Finally, we explore the effects of a culture in which drawing on personal experience is a valid strategy for model design and creation.

Conceiving of the Model

Both the Activities that we conduct and the models that teachers build are based upon the actions of individual agents and their interactions over time. During the Activities, we encourage teachers to think about both their own individual role (for instance, as a Humanboid or a fish) and the behavior of the whole group (like the flock or the pond). With some Activities, like Humanboids or Papercatchers, we specifically ask participants to pay attention to the rules of the game and reflect on how those rules affect the behavior of individuals and influence the system-level patterns they observe.

As Cathy mentioned earlier, the Activities helped her to think about the relationship between "the part", or the individual, and "the whole". The experience of being part of an agent-based model helps people think about how to build their own agent-based models, by giving them an alternative perspective on some of the issues that they face during model design and creation. Some groups make use of this connection when developing ideas for their projects:

> Dick: So I thought one of the interesting things was the way we went into designing the project. Rather than going directly to the computer and starting to manipulate screen variables and such, we decided to walk outside. We discussed it as we were walking. Once we got to a point where we could come to some agreement as to a common vision, we just stopped. We sat down. We decided what our turtles were going to do. Then, we decided how our turtles were going to interact. We thought well let's start using the environment. So we're on the sidewalk, we've got turtle patches in the form of squares on the sidewalk. So in order to take a look at how these turtles might interact, we started hopping, becoming the turtles ourselves. (Challenge 6 pinup)

Explicitly thinking about themselves as turtles (or birds or fish) grows out of the Activities we engage teachers in.

Utilizing Experience

Ultimately, we want teachers to be able to draw upon their own personal experience when they are building models. But not everyone knows intuitively how to tap into that experience (and it is often not clear to people that drawing on personal experience is an acceptable strategy—most people think that scientific modeling, or any kind of science, must be completely separate from personal experience (Keller, 1983)). We use Activities both to give them experiences that they can draw upon and to validate the strategy of drawing on other experiences that they have.

During the first few days of the Workshop, we engage teachers in Activities that can be translated directly to computer models. We adopted this strategy because the initial stages are the hardest time for novice model builders to generate their own modeling ideas from scratch. Explicitly allowing, and encouraging, direct appropriation helps convince teachers that connecting experiences they have had to models they are building is a valid strategy.

Many teachers draw specifically on the experiences they have in the Activities when they are building their models. During the Pixelated Paths Activity, the turtles (which are simply drawn on graph paper) follow three rules:

- If the patch color ahead is blue, then turn right
- If the patch color ahead is green, then turn left
- If the patch color ahead is red, then turn all the way around

Like many other groups, Julie and George used these rules when they built their project for Challenge 3.

Julie: When we did the graph-it [Activity] the other day, I hadn't done anything with diagonals, so I thought it would be kind of interesting to do diagonals, but diagonals on graph paper and diagonals on the computer are a little bit different. Obviously, one of our biggest problems was the intersection point in the middle, and it took us a long time. In fact, we left yesterday with half an intersection, and we came back this morning and worked out the details on the rest. We don't quite have envelope right now, we have barn door. And, we'll show you what it looks like so far. (Challenge 3 pinup)

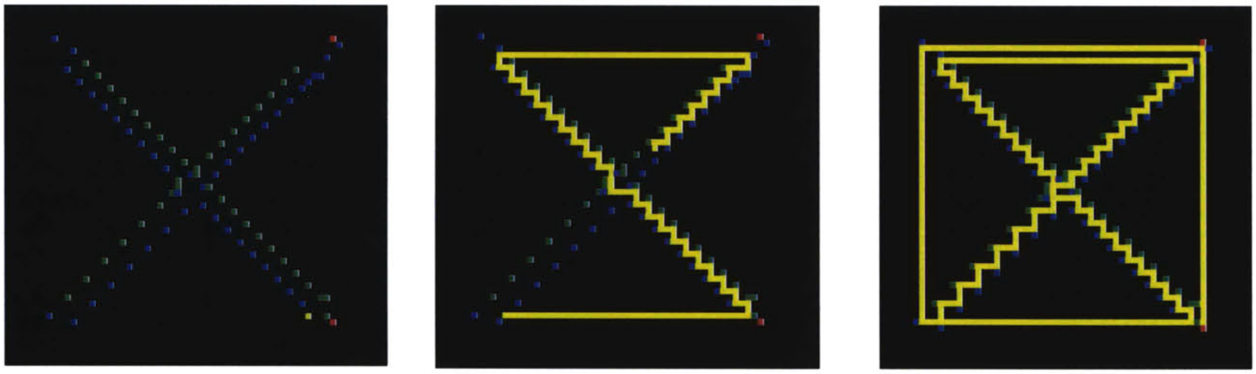


Figure 12: George and Julie's barn door project. As the turtle moves through the environment, it turns at each obstacle and draws a yellow path wherever it goes.

Of course, there are a limited number of Activities that we can conduct during a Workshop. Our aim in validating the strategy of "drawing upon the things that you already have experienced" is to broaden the scope of things that teachers bring into their models—to include systems that intrigue them.

In Challenge 5, Ivan, Sylvester, and Max worked on a forest project. One thing that they focused on was creating a process that would make the trees grow into a pointy pattern at the top. Generating the rules to make the trees grow with points was a difficult task. With some encouragement from the Workshop facilitators, Sylvester describes how he drew on his own personal experience when he designed the tree growth algorithm.

Vanessa: I have a question. Can you show the code that made the trees be pointy at the top instead of—

Sylvester: No, that's top secret, we don't allow it [laughter].

Ivan: You'll have to kill us.

Sylvester: Where it says stamp green towards 180. No, that's not it. Go down a little further. There it is. See where it says if Y coordinates equals minus 60, etc. etc. Grow foliage, stamp towards 90 1 green, stamp 270 1 green, stamp towards 180 green, and then it says stamp towards 180 2 green.

Eric: How did you come up with that?

Sylvester: Well, it was just logical, you know [laughter].

As a former cartographer, years ago, I remember doing something like this. In Vietnam I had to draw a map, and I had to show a possibility of coordinates that could happen on what they call a Decca unit, which was something we were drawing up for F-100s to bomb a certain area. There was a variable involved.

You could go a certain direction this way or that way. So that's what I came up with from that. You always associate things you know from the past. (Challenge 5 pinup)

```
to check-patches
 if pc-ahead = brown [die]                    ;ground color
 if pc-ahead = 137 [stamp green]              ;seed color
 if pc-ahead = 8 [setintensity intensity * 0.7]  ;filtered by cloud
 if pc-ahead = green [if ycor < -60           ;grow tree trunk
                        [stamp green
                         stamp-towards 180 1 green
                         stamp-towards 180 2 green
                         stamp-towards 180 3 green]
      if (ycor >= -60) and (ycor < 0 )        ;grow foliage
                    [stamp-towards 90 1 green
                     stamp-towards 270 1 green
                     stamp-towards 180 1 green
                     stamp-towards 180 2 green
                     if (intensity > 10) [stamp-towards 180 3 green]]
                                                  die]
end
```

Figure 13a-b: For Challenge 5, Ivan, Sylvester, and Max worked on a forest project. Sylvester contributed the "pointyness" of the trees (a). Though his code (b) is quite complex, for Sylvester it was simply "logical" since it grew directly out of his own personal experience with map building.

Sylvester is a very traditional teacher, who earlier asked:

Sylvester: Is there anyplace we can go and find some sophisticated modeling programs that people have done? One of the things I would have liked to have seen—what is the actual possibility or what are the possibilities that StarLogo has the ability to perform? I would like to see that. I want to see something really complicated, and I can work from simple to complex. (Workshop discussion)

Sylvester's mental model of how he learns is that he looks at a complex model and then figures out how to build it. This approach to learning is not uncommon. Many people approach problems as though the problem is completely disconnected from their own experience. In fact, making connections between past experiences and present conundrums can be a powerful learning strategy. One of Sylvester's most significant modeling achievements (the pointy trees) came not from 'trying to make something really complex' but from applying an old memory to a problem at hand. In some sense, he is using an analogy to derive a solution to the challenge of building the pointy trees. It is this ability to think about the relationships between patterns and processes in the world and in the model that characterizes the kind of learning we were trying to achieve.

Adopting a Modeling Stance

The whole point of the Adventures curriculum is that modeling becomes a tool with which people can view the world in a different way. Both connecting the Activities to personal experience and using experience to build a deeper understanding of model creation and exploration are part of that process. When teachers view modeling not as learning a single software package but instead as using a tool to think about the world in a new way, we have an important goal for our modeling culture. The Activities and the Participatory Simulations illustrate the general nature of modeling as a tool, by showing how modeling can occur in different media (as opposed to imparting the idea that modeling is exclusively about learning to build StarLogo projects). These experiences also help people to better understand how to do things in StarLogo and form a bridge between how teachers viewed the world before they adopted a modeling "lens" and how the world looks through that lens.

As people develop fluency with modeling, through their experiences in the Activities and the StarLogo models that they create, they begin to see the world a little differently. They begin to draw connections between Activities, models, and ultimately, real world phenomena. One of Carl's students participated in the virus games twice (during computer class and later during science class):

> Carl (a computer teacher and technology coordinator at a suburban private school): One of my students had a [science] class later in the day... After a while [he] just could not contain himself, and he raised his hand and he said, 'Mr. Simon couldn't we use StarLogo to explore this much, much faster with a lot of other situations?' It was wonderful to see. He was ready to go, and in a few weeks he will be able to actually do this in that class. (Reunion)

Concurrently engagement with Activities, Participatory Simulations, and computer models helps people to build strong connections between different types of models and the phenomena they represent.

Validating Existing Pedagogical Strategies

Our sustained commitment to learning through Activities throughout the Workshop illustrates by example our belief in the power of that type of learning experience. Of course, we are not the first people to realize that people learn best through experience (e.g., Brehmer, 1980; Dewey, 1988; diSessa, 1986; Kleiner & Roth, 1997). Almost every science teacher will explain the importance of hands-on activities and many teachers, especially in the middle and high school, rely on activities to teach their own students. Our reliance on learning through Activities is an endorsement of the very same techniques that many teachers are already comfortable with. This strategic alignment helps to implicitly connect our aims and the teachers' aims. Teachers can see that 'thinking with models' connects to aspects of their existing practice.

During the final pinup, Noah describes how he sees the modeling we did in the Workshop as connected to his practice:

> Noah: As teachers we use lots of different kinds of models. And I like using models in my classroom. And I have a whole slew of them. And if you're a middle school or ninth grade science teacher, you probably have a whole slew of models that you use… I chose to develop a StarLogo model for the phenomenon osmosis and diffusion.
>
> The sequence of events is the kids will come into the classroom one day and it will smell really awful in the classroom. And on the desk will be some cheap Demulus kind of baggies with slices of onion in it. And they go: 'Oh, it smells awful in here.' I say: 'It can't. The onion is in the bag and what do you think is happening?' And they'll say: 'Well the onion smell is getting out.' And I'll say, 'well how do you think that's happening.' And this might help them to visualize it. And so they'll say: 'Oh, the smell is getting out and how do you think it's happening? Maybe there's little spaces in there that the smell molecules can get out.' And this kind of thing can help them visualize that. And it's very simple. It's not all glitzy like some of the others. I think it's a good place for students to start getting used to this kind of thing. And I purposely chose a system, an area that we get into early in the year so they can start to get used to this kind of thing—of a parallel physical model, computer models.
>
> This would represent some osmosis. And in conjunction with osmosis, I use several different models. And one, the kids will put a piece of potato in some water and weigh it and the next day it will come back and it will weigh more. And so what happened, well, the water went in. And I asked them, well what do you think is happening there. And say maybe the water is going into the cell. And then after they do that, we use an egg as a model. So I can pass that around. You put the egg in some vinegar and the vinegar eats away the shell of the egg. And now they have this as a model of a cell. So there are all sorts of models going on. So, now can you visualize what might be going on.
>
> Then, the student says, well what really happens with that egg, it doesn't stay the same size, it swells. And so then we instituted a system with—all of this was with the help of the Workshop people—to develop a movable membrane. So that if there's more water molecules on one side than the other, then the egg will shrink and swell. And you can also—this is sort of an evolution of a model. You can add more sugar. And eventually the egg will swell.
>
> So it's a use of a model, of a computer model, to help visualize what's going in the physical model. So it interacts with the physical model. There are data collection opportunities here that there isn't in the egg model, which is really cool. So again you have various levels of models. You have physical models of various sorts. And then you have this model. And you can use it in conjunction. I think what's really important, one of the things that I want to do is, again, is to start early with these models so that it becomes a regular part of the class. If you wait until the spring when you're studying ecology, to all of a sudden start, then the kids aren't used to it. If you get them started early with simple stuff, they can understand and use the more complicated ones. (Final pinup)

Learning to create computer models was a new experience for Noah. The opportunity to place this experience within a pre-existing pedagogical framework enabled Noah to weave his new knowledge into his teaching practice. Connecting computer modeling and Activities gives teachers a clear picture of places in their curricula where they might introduce new ideas about modeling. In the case studies in Chapter 7, we will further explore how our approach of including Activities aids teachers in their attempts to change their practices.

First, we turn to an examination of how Activities and other aspects of the Workshop structure create a strong group culture. Activities not only engage people in a group experience, they also engage the group in discussions about that experience. Both aspects contribute to the growth of a community of practice for our modeling activities. In the next chapter, we look specifically at the development of social context and the emergence of a community of practice at the Workshop.

6. Building a Community

One of our primary goals during the Workshops is to create a social context for research and discovery among teachers. The rationale for this goal is twofold: first, we want teachers to participate in a process that mirrors those undertaken in the scientific community, in which ideas grow and take shape through interactions with colleagues. Second, we want to encourage teachers to create similar communities among their students, and we feel that one good way to encourage such a modification in teaching style is to model the same style during the Workshops.

In this chapter we will revisit the notion of the social context of scientific practice and how a community of practice supports and facilitates scientific discoveries, paying special attention to why we chose to focus the Adventures Workshops and book around such communities. We will then look specifically at the structures within the Workshop that we created to facilitate the rapid construction of such a community. We will explore the ways in which teachers' participation in this community manifested itself during the Workshop. Finally, we will discuss the dissolution of this community as the school year began, offering some suggestions for keeping it going.

The Role of Community in Scientific Research

The goal of the Adventures in Modeling Project is to engage teachers, and their students, in authentic scientific practices through modeling. Though a popular conception is that science is a solitary pursuit, it is actually a highly social endeavor. The reality is that scientific practice is a largely collaborative (and sometimes competitive) enterprise, and the extent of collaboration is on the rise (Kraut et al., 1990). For example, recent announcements about the human genome project reveal how collaboration and competition shape the social context in which scientists conduct investigations and make discoveries[12] (Wade, 2001).

We are interested in fully developing teachers' abilities to engage in investigations and discoveries using modeling. Just as in scientific practice, these investigations and discoveries are not about a phenomenon revealing itself—they are about convincing others in the community that a particular interpretation of a phenomenon is worth following up on (Latour, 1987). This stance is especially important when considering the important role that communication and articulation play in teaching and learning. The model of a "community of learners is based on the premise that learning occurs as people participate in shared endeavors with others" (Rogoff, 1994). As in scientific communities of practice (Lave, 1991), communities of learners work together to construct knowledge.

In designing the Workshops to foster authentic scientific practices we did not look at training teachers in the use of specific scientific tools but instead focused on creating a scientific community of practice. Through this community, we showed teachers the important benefits that emerge from sharing both technical knowledge and higher-level ideas and insights. It is

[12] In that project, not only are researchers competing to be the first to make discoveries, they are also sharing data and adopting similar techniques.

these discussions that replicate the best of the scientific world and are most likely to facilitate discoveries and enable the development of new knowledge. We structured the Workshop to provide access to four key elements of scientific communities (Dunbar, 1995). Namely, that members of a research group should possess different but overlapping backgrounds, work with one another to highlight inconsistent or surprising findings, rely on analogical reasoning to explain ideas and hypotheses to others, and enjoy opportunities to interact and discuss research.

Fostering a working scientific community is quite difficult, in part because a "real" scientific community relies on the commitment of its members over time. Nonetheless, we made a number of design decisions for the Workshop that helped us to provide rapid access to certain aspects of a research community.

Building Community through Shared Experience

Central to our conception of "Adventurous modelers" is that they will use modeling as an avenue for creation, discovery, and exploration of issues or topics that they want to explore, and that participation in a community of practice will be a primary enabler of these activities. The organization of the Workshop facilitates the rapid development of such a community. Though the majority of the teachers in the Workshop didn't know any of the other participants, we wanted the group to coalesce into a tight, functioning community as quickly as possible. To solidify our nascent community of practice, we engaged participants in group Activities and discussions, and we relied on these group interactions to provide the substance of the Workshop. In other words, the group interactions were not just social; they were the content of the Workshop. If teachers wanted to be involved in the intellectual development opportunities at the Workshop, they needed to fully participate in the community.

Since all of the teachers came to the Workshop with differing backgrounds, we paid special attention to creating opportunities for teachers to develop overlapping experiences. The Activities provided common experiences and the modeling Challenges gave people common problems to explore. We pushed people in the direction of analogical reasoning by helping them to connect modeling to their lives and to Activities (as discussed in Chapter 5). The pinups and desk-crits (described in Chapter 3) provided opportunities for people to articulate their ideas and solicit feedback from their peers, and also highlighted the premium we placed on intellectual exchange during the Workshop.

The Workshop structure ensured that teachers would learn primarily from one another—building on each other's successes, supporting one another, critiquing and improving models—and not depend solely on us for information. And, we hoped that this community would be one of the pillars that sustained the teachers as they used StarLogo and modeling back in their own schools.

Activities

In addition to helping teachers increase their comprehension of modeling (see Chapter 5), the Activities served to quickly grow a strong community of practice. Specifically, they provided two important aspects of that community: first, they gave participants a diverse set of common experiences to draw upon, and second, they facilitated dialogue around modeling issues.

The Activities involved participants in unique, fun, motivating experiences. Like members of any community, Workshop participants all came to the Workshop with different backgrounds. The Activities, along with the modeling Challenges, gave participants common experiences to which they could refer. These experiences allowed participants to form social bonds, and they provided participants with a common history. For instance, after Humanboids, all of the teachers understood what Noah was talking about when he brought up human "flocking" during a conversation. The teachers' mutual knowledge, shared experience, and common developing language (e.g., "yupping", "turtles", and "`seth`") were important components of their growing culture. Very quickly, the teachers had similar experiences to balance the different backgrounds that they brought to the Workshop. The diversity in the group enabled participants to learn from each other and ensured that everyone had a unique perspective to contribute.

The social bonding that occurred is very similar to that in other team-building games. But, unlike other team-building activities, the Activities we ran asked participants to grapple with issues that are essential to designing and creating agent-based models. The content of the Activities is central to the same domain that the community was building its expertise in. The discussions during and after each Activity were forums for teachers to learn to relate to one another in a conversation about modeling ideas. The Activities provided a framework for social and intellectually relevant connections among participants. The formation of these domain-based connections is a key to the development of a vibrant community of practice.

Challenges and Pinups

The modeling Challenges balance structure and open-endedness. By articulating a specific design goal, they provide a common direction for learners to take as they build solutions. This commonality ensures that the teachers can learn from each other's solutions because those solutions share some common features. At the same time, the Challenges do not overly constrain the kinds of solutions people can create, allowing teachers to pursue ideas of interest to them. 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 Challenges serve to point all of the teachers in a common direction for exploration and creation. But it is the pinups that directly facilitate public discourse about models. The pinups are a forum for discussing specific modeling insights as well as ideas about using models as learning tools. In this section, we describe some of the ways that teachers make use of the pinups to solidify their own understandings and learn from each other.

Learning to Program

Earlier, we discussed the fact that we do not want to stand up at the front of the room and teach the teachers how to build StarLogo models. Yet, programming is a key component of model building, and many of the teachers come to the Workshop with absolutely no programming experience. The pinups are a principal venue for teachers to learn bits of code from one another.

Teachers participate in their first pinup on the first afternoon of the Workshop. During a pinup, each group presents their Challenge solution and discusses a key insight or difficulty that they had during the Challenge.[13] The facilitators model a style of questioning that is designed to solicit information and ideas from the groups as they present. We ask questions about high-level goals of their models as well as particular features of the model. By the second pinup, on day two, the teachers are already making the same kinds of inquiries, about topics of interest to them.

In this exchange, Will, Ivan, and Richard are presenting their model of electric currents.[14] Will describes how certain colors, which represent "beams of light", cause "electrons" to bounce off of the blue "screen" at the base of the model.

> Will: So any color that's less than 115, when it hits the screen, is going to die because it gets absorbed. Any color greater will cause an electron to jump off. So, what we programmed it to do is if the color is less than 115 it dies, and if it's greater than 115, you get a white streak that jumps off, which is supposed to be the electron.

Noah asks how they made the turtles (which are the beams of light) create a white streak across the canvas:

> Noah: How did you get that white streak?
>
> Lawrence: `Pendown`?
>
> Richard: We changed the color, right?
>
> Noah: What's the command for creating a white streak?
>
> Dick: `Pendown`.
>
> Will: Let's see. Right here.

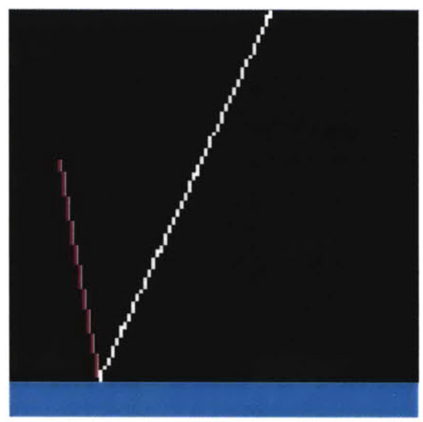


Figure 14: A magenta light beam bounces off the screen, causing an electron to jump and leave a white streak in its path.

The group members discuss the two components of creating the white streak. Dick mentions making sure that the turtle has its `pendown` so that it is drawing a path, and Will and Ivan describe the `if` statement that they used to determine whether or not the turtle should change its color to white and draw the streak or die (be absorbed).

> Ivan: Didn't we use the `if` statement?
>
> Will: Yeah, if the patch color ahead is equal to 85, and if the color—
>
> Ivan: Is greater than 115.
>
> Will: —if the color of the turtle is greater than 115.
>
> Ivan: Or if it's in a band.
>
> Will: Then it says, take a left turn at 145 and set the color design so it bounces back out white. (Challenge 3 pinup)

---

[13] See Chapter 3 for more on the structure of pinups.

[14] This model was first described in Chapter 4.

At this point in the Workshop, none of the teachers views him or herself as an expert modeler. Yet, they exhibit a high degree of comfort and willingness to teach each other the things that they have learned about modeling. These interactions are one of the first indications that they are becoming members of a community of practice.

```
to check-patches
 if pc-ahead = 85
   [if color < 115
      [die]
   ]
 if pc-ahead = 85
   [if (color >= 115)
    and (color < 139)
       [lt 145
        setc 9]
   ]
end
```

In English this code reads:
If the patch ahead is blue (color 85)
    If my color is less than 115
        Then die (be absorbed)

If the patch ahead is blue (color 85)
    If my color is greater than 115
    and less than 139 (in the "color band")
        Then turn
        and set color to white (color 9)

Figure 15a-b: Will, Ivan, and Dick's code from their project on electric currents, left, with an English translation, right.

In addition to teaching each other particular commands, the teachers begin to share modeling heuristics. Here, Bea and Ivan are discussing Ivan's use of a button, called "start", that caused four other buttons to turn on and off in sequence, enabling him to control his model with the click of a single button.

> Bea: I was wondering, you said you had the sequence—the buttons hit all the other buttons. How is that different? I mean, what is different about that from having it just read the code?
>
> Ivan: Actually, we probably could have written all the code again into a button, but we just found, because the only way we could make this run was to go through the four buttons that are above the start button, so then we had the idea of putting a start button in and incorporating all four of the buttons just to save time. (Challenge 3 pinup)

A few moments later, during her pinup, Julie comments that she could have used the same concept in her barn door project.

> Julie: For us, his start button, their start button from the last one would have been great, because we could have incorporated the die, clear path, start setup, and then just hit a start button and that would have been great. (Challenge 3 pinup)

The teachers are beginning to rely on one another to learn about building models. One must keep in mind that it is not the size or significance of any particular idea that is exchanged that is important—it is the fact that already, on the second day of the Workshop, they are turning to each other as resources instead of relying primarily on the Workshop facilitators.

Admittedly, this process does not happen without some encouragement. Sometimes, one group discovers and incorporates an interesting idea into their model, but none of the other groups is at a point where they can see the relevance of the idea. At these moments, we facilitate the conversation by modeling the kinds of questions we think the teachers might want to ask. Cathy and George built a model of children pulling toys out of the toy box and leaving them on the floor while the parents ran furiously around the room trying to put away the toys. They incorporated a monitor into their model, which counted the number of toys on the floor.

> Vanessa: I have a question. Can you show people how you made it say how many toys were on the floor?
>
> George: The counter?
>
> Vanessa: Yeah.
>
> Cathy: We counted the patches. The way we distinguished a toy on the floor from the toy in the box is by a slightly different color. That way the children knew which ones to pick up, and the parents knew which ones to pick up, but also we can count the patches that are the color 108, which is that lighter blue of the toy on the floor, and that just returns that [number]. And the same for the toys in the toy box; that counts the patches that are blue, which is this color in the toy box.
>
> Liz: So what's happening is the turtle is going over and picking up the dark blue—
>
> George: Yes.
>
> Liz: —and stamping a light blue on the patch.
>
> George: Yes.
>
> Liz: So then, when the turtle hits a light blue patch, is it stamping it black then?
>
> Cathy: No, it depends on. Yes. It depends also though on what color the turtle is. If it's a green turtle, it's only looking for the light blue patches, which are the toys on the floor; that means it's a parent. If it's a yellow turtle, it's looking for the dark blue, the brighter blue, which is the toy in the toy box. (Challenge 4 pinup)

Once I asked Cathy and George to explain their toy count monitor, other teachers began to see aspects of the idea that might apply to their own modeling efforts.

Exchanging Strategies for Learning

On the fourth day of the Workshop, we held a discussion for teachers to air their experiences and concerns. Significantly, it was not just the facilitators who saw the value in the pinup exchanges:

> Liz: I feel like the information gained from the pinups is really, really important and that because you have all these people that are working on it, you get a lot of different views, and I've learned an incredible amount of what other people have said. (Workshop discussion)

Yet, we do not always follow our own plans. Occasionally, the constraints of the Workshop cause us to move too quickly from one Challenge to the next. More often, the desires of teachers to present "finished" models push the pinup too far toward the end of a given Challenge. Liz continued:

> I just feel like what I'd like to do is work on a project and half way through it do a pinup, and then go back and use all the information that other people have gathered and maybe either make that one better or, you know, all of sudden say, 'Oh, that's how I should've done that' and do that. Because I feel like we don't get to use the information we're learning in the pinup fast enough. (Workshop discussion)

Her concerns led into a conversation among the teachers about the strategies they used to garner as much information as they could through the pinups.

> Noah: I see all this cool stuff [in the pinups] and I'm afraid I'm not going to be able to use it. I'll say, 'I remember it was in their presentation, but I'm not familiar enough with the language that I could think it.'
>
> Lisa (a business teacher at a rural high school): No, but what I did while that was happening, I wrote down who it was, what the name of their thing was, so now I can go over there and steal it.
>
> Lawrence: I went a step further in my learning style. What I do is every 40 minutes I get up and walk around and as soon as I see something that looks really cool, I know it in my head what the file name is. I wander over and I open up their file, and I just snag whatever code I want.
>
> Unidentified speakers: Yeah, me too. Yeah.
>
> Lawrence: Which is the accelerated learning curve. (Workshop discussion)

In this example, teachers not only share the methods they have developed for building on each other's projects, they also exchange their strategies for learning from each other and from the pinups.

Cathy commented on how the pinups affected her learning experience:

> Cathy: I had never heard of [`sprout`] before, so I was really glad that that was mentioned because I was thinking, 'Wow, that raises some possibilities I wouldn't have thought of.' (Workshop discussion)

A consistent thread that runs through our research is the importance of helping teachers to learn through modeling, not just learn about modeling. The pinups serve as both a forum for exchanging tidbits of knowledge about creating models and sharing strategies for learning about modeling.

Distributed Expertise

We have been discussing the kinds of knowledge that teachers share with one another, but it bears noticing that they look to each other for knowledge at all. When teachers show up at MIT for a computer workshop, they are almost always waiting to hear what the "experts" have to teach them about computers. In our Workshops, we work very hard to make the teachers responsible for their own learning experiences, and we structure the Workshop so that those experiences are had primarily with other teachers. Nonetheless, it would not be difficult to imagine that teachers would be willing to learn some small things from each other but would look to the Workshop facilitators as the ultimate arbiters of technological knowledge. Such a result would be a disappointment because it would indicate that our social context was pleasant but not functional in terms of enabling teachers to help each other more fully explore and understand the modeling domain.

During the final pinup, two teachers put these concerns to rest. As they explained their project, a volcano that spewed lava, which in turn formed various types of rock, Sandra and Liz articulated how they made a series of crucial programming decisions. In this case, they were deciding whether or not to make a part of their volcano out of turtles or patches. Though the Workshop facilitators gave them advice, they relied on each other to make a final decision.

> Audience member: Well, this is a rather technical question, but it seems that deciding what to do in terms of putting things into patches or into turtles, how did you figure that out?
>
> Sandra: Well, not well. As I say, we spent about four hours making a turtle volcano. And then one of our esteemed leaders said: 'I don't know why you're doing that, they should really be patches'. So then we had, after she left—we won't mention any names—Liz said to me: 'I don't care what she says, we're not changing it, it would be too much trouble'. Because we'd spent three hours programming `if` dah dah dah, `set`, dah dah dah. So basically it's a question of 'do you want them to move or do you want them to be stationary?' (Final pinup)

Initially, Liz simply stated that she was unwilling to take this advice on the project. However, it became apparent that they reached their decision by working out the problem together. Their solution was a well thought out plan, not just an attempt to thwart the facilitator.

> Liz: But the problem as far as deciding it's pretty critical. The reason why I said what I said was because one thing impacts another, it doesn't live in isolation in the programming. So if we change these back into patches, now all our `if` statements and all our `ifelse` statements are dependent upon whether or not they hit a turtle or a patch, are all related to this. So because we didn't do it originally, it will be difficult to change it.
>
> Sandra: Can you show the lava again? This is what we ran into. When we started to follow Vanessa's suggestion that we turn these back into patches, Liz said: 'This isn't going to work.' I said: 'Sure it will, why not?' She said: 'Well let me show you.' So we spent ages struggling with how to get the lava to flow, to bounce up and down like popcorn, but also to flow on either side of the mountain and not come down the front of the mountain, which was the cross section. And when we tried to turn those back into patches, that's what it did again. (Final pinup)

These teachers achieved a level of comfort with their own understanding, and in their relationship to others in the group, that they were willing to publicly discount "expert" advice from the facilitators, relying instead on their own conception of the problem and its solution. This level of confidence in and willingness to defend their hypothesis to the group, even in the face of known dissent, characterizes an aspect of scientific communities that we were pleased to see emerge (Latour, 1987).

Communities Creating Knowledge

Communities of practice are not wholly concerned with the people that embody them. They are also concerned with the kinds of accomplishments that the community seeks and attains. In addition to how people feel about working with one another and the smaller scale pieces of knowledge that they learn from one another, it is important to see what kinds of larger scale advances the group is able to make. Often, these advances are more dramatic than those that any single individual could make in the same amount of time and with the same amount of effort—this is why science functions as a community. Members of the community building on the achievements of others increases the amount and caliber of knowledge that the community can construct.

In this section we look at one extended example of the creation and refinement of an ecosystem model. We profile this project from its initial appearance in Challenge 3, when teachers had very limited modeling skills, to its debut in the classroom. During the development of this project, many different teachers participated, some only briefly. A few people made contributions of critical importance, even though they never worked on the ecosystems model itself. And, in the end, a model emerged that was quite sophisticated.

A Game of Pool

The pond ecology project began as a model of Billiards. In Challenge 3 (day 3 of the Workshop) Dick and Tony built a model of pool. The turtles start in the center and then bounce around the environment randomly. When they hit a corner pocket, they disappear. During the pinup, they explain that the next feature they want to add is that turtles would reproduce when they hit a "patch" pocket.

> Tony: We're just in the process, but didn't have a chance to create some patch pockets, which are these. What we wanted to do is if they hit this, it dies. If they hit one of these, then they would hatch like four. Then, you could run it and sort of see where you end up after awhile.
>
> Sandra: You'll eventually end up with no turtles?
>
> Dick: Well, we've got three left.
>
> Tony: Yes, the way it's set up now, you're eventually going to have them all die, because we don't have a source for reproduction. If these were activated, then it would be interesting to see what would happen. I don't know where the equilibrium would lie. (Challenge 3 pinup)

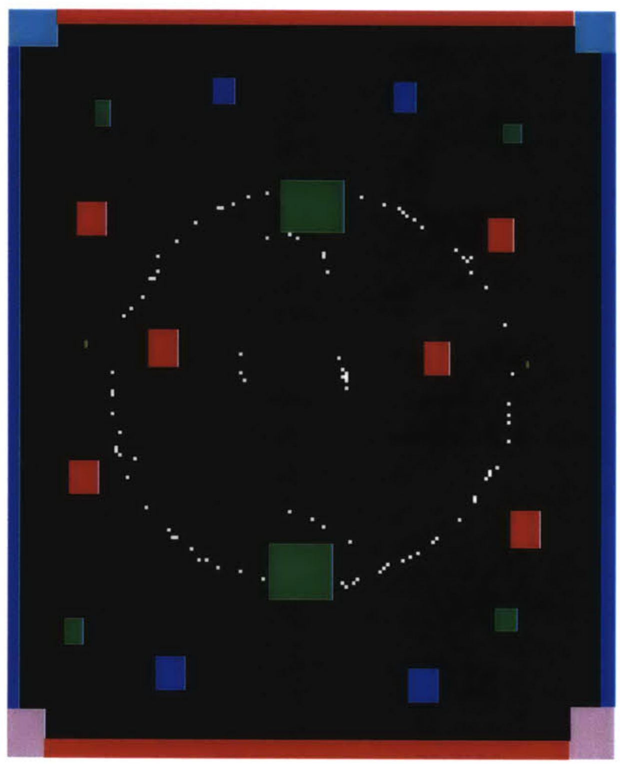


Figure 16: The Billiards model, created by Tony and Dick for Challenge 3.

Tony explains that without the "patch" pockets, which cause the turtles to reproduce, the turtles will eventually all die (by falling into one of the corner pockets). However, if he and Dick were able to include reproduction, some turtles would die while others were reproducing, leading to a qualitatively different kind of model behavior.

Later in the pinup, Tony and Dick muse about what this project could model. Tony offers the idea of building an ecosystems model and Dick discusses how this project could be thought of as a mathematical function.

> Tony: This started off, basically, as like when we were trying to invent a game, a sort of an offshoot of billiards. That's kind of the original idea. But it could be used to model—this is like a good ecosystems model. I mean, we still have to do some work to it. But, you've got, you know, these could be, you could make these food patches. Like, let's say the red were food patches, and every time a turtle hit a food patch, its color would change, and that could represent an increase in its fitness or reproductive capabilities. Then, these, I don't know, could be—then you'd have your predators out here as well. And if they hit that they would just die. And then you'd have like, I don't know, spawning habitat, or whatever you want to call it. If they hit that, they would reproduce based on their energy level. So if they hit lots of food patches, they'd reproduce five, and if they only hit one food patch, they'd reproduce one.
>
> Dick: Also we were looking at this, and because the turtles change colors, this could actually be a game for probability as well. At certain points, you can stop the game, and you can see what percentage have actually changed and actually come out with a probability equation to show what happens. And thus, this could actually become a function itself. (Challenge 3 pinup)

Discovering Reproduction and Contemplating Ecology

As they were describing their Billiards model, Dick asked if anyone wanted to help them implement the patch pockets that would cause reproduction:

> Dick: Would somebody like to help us with that code? We'll put it in. (Challenge 3 pinup)

None of the other teachers offered the solution to the reproduction issue during the pinup, but Dick followed up on it. In Challenge 4, he and Noah created a completely unrelated model of picnickers being attacked by mosquitoes near a lake. Instead of creating the picnickers in a setup procedure (the most common way to set the initial conditions for a simulation) Dick and Noah used special patches on the screen to "sprout" the picnickers.

> Dick: OK, what we did was we created these [mosquitoes] and these poor picnickers. When these picnickers get bit, the bug will go back to the lake, with the blood, and then it will hatch a new purple bug. Eventually, we see that we have a new population of mosquitoes.
>
> Noah: We learned a bunch of things. What we did was, in order to create, like, a shape of turtles, what we did was—I can't remember now.
>
> Dick: Sprout.
>
> Noah: Was sprout was the command. We created a black patch, and then the black patch will sprout the turtles of a certain color, and then you can give them all that instruction. So that was really cool. (Challenge 4 pinup)

While Noah and Dick discovered how to `sprout` turtles from particular patches, Tony worked on a forest project, perhaps spurring him to think more about modeling ecological interactions. The experiences of various teachers in Challenge 4 laid the groundwork for some major advances during Challenge 5.

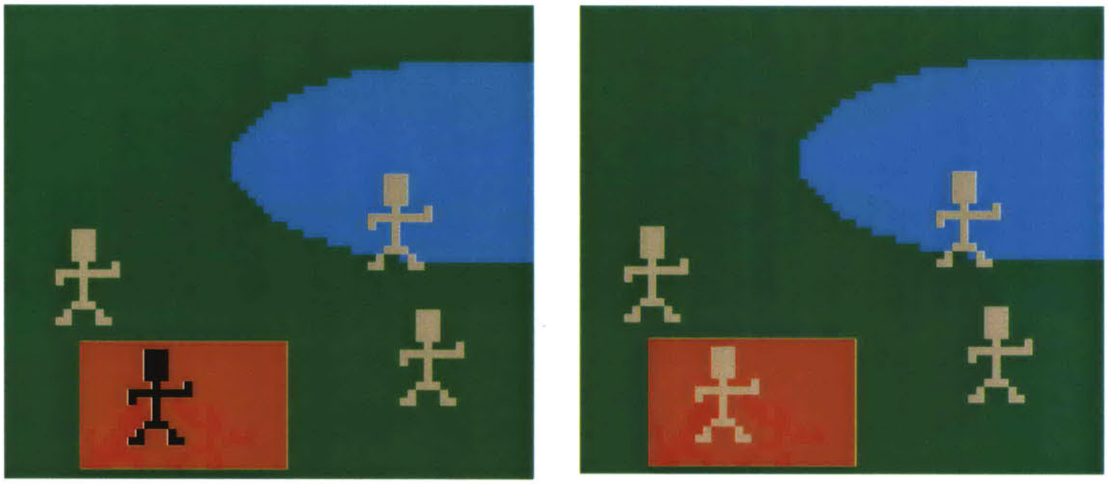


Figure 17a-b: Instead of creating the picnickers using a setup procedure, Noah and Dick directed the black patches to `sprout` turtles whenever the picnicker button was pressed. A separate procedure moved the picnickers around the screen.

Creating "Valid" Models

In Challenge 5, two important milestones were reached by the group: Noah and Cathy began what will become an extended group discussion about the validity of a model and Tony and Lawrence built the first ecosystems model.

Calibrating and Exploring Models

Noah and Cathy created a model of people, with varying degrees of genetic resistance, encountering stress in their environment. Users can set both the genetic predisposition to being affected by stress and the severity of stress in the environment. During their pinup, Noah and Cathy raised the issue of the relationship of their model to reality and discussed what steps they took to create a valid model:

> Noah: What I realized, and what we realized, was that in setting the variables that you could affect the outcome of the simulation. We realized that if you want to make the environment more important than the stress, then you set the environmental variables to a high level, but if you want to set the genetics more important than the stress, you set the genetic variables to the high level. When you run the simulation, you get a certain result. So I guess it's a word of caution to folks that when you do your simulation, you've got to make sure that when you start setting variables that either you have a purpose and you want to achieve that purpose, regardless of whether the relationship really true or not, or you want to check the data and make sure the variables correspond to reality, as best you know it.
>
> Cathy: One of the things that we were tinkering with a lot is like we wanted it to be visually useful, as far as the sliders go, so that if the sliders are all in the middle, this should be sort of an equilibrium where most of them are average in health.
>
> Noah: Yes, that's a real key, and Cathy figured that one out. We said, if we set the things—and we didn't know what to set these at. She said, yes, if we set everything in the middle, then we should get a range around the middle of whatever we're talking about, here it's health or energy or whatever. It took quite a long time. It took quite a long time to set that. Anyway, that was ingenious; we said, 'yeah, we'll set everything in the middle'. We'll keep working it until these come out so that everything is average, and

> then you know that's the middle of your range. It's sort of hard to explain, but once we got to that point of actually having a model, it's how to tease it so that it was representative of a reality that we thought was [reasonable]. (Challenge 5 pinup)

This comment began an extended community-wide conversation about realism in modeling (see Chapter 4). They also introduced their initial investigations with their model. Here, Cathy described the proportion of very healthy people, explaining that a few minutes ago most of the people were sick but now they are quite healthy. She also proposed an experiment to judge the impact of genetic resistance on the two populations.

> Cathy: Right now, it's a little slanted towards very healthy, but a few minutes ago most of them were very sick... [So] we can try different trials and say 'What if the environment stayed the same, we had the same amount of environmental stress at the same severity, but one population is less resistant and one population is more resistant?' Then you could observe and compare with the monitors. (Challenge 5 pinup)

Up until this point, most teachers in the Workshop have focused on designing and building their models. Here, Cathy and Noah introduced the idea that, when modeling, it is also important to explore the patterns and processes that a model exhibits. They highlight the roles that testing the assumptions in the model, calibrating its variables, and investigating the model's behavior play in scientific modeling.

Building the Fishpond

While Noah and Cathy were advancing the community knowledge around issues of modeling in general, like model validity and testing hypotheses and assumptions through experimentation, Tony was working with Lawrence on the first implementation of the ecosystems model:

> Tony: So we wanted to create a simple ecosystem with a producer species and a consumer. This program, actually, we've run into some complexities that we've been trying to overcome, and haven't had much success with, at this point. I don't really even remember, at this point, exactly how to explain what was going on, but maybe if we went into the—where is that, in the observer procedure?
>
> Lawrence: The ultimate goal was to—this is science stuff—was to have fish that went through certain maturational stages. Early on, they just swam around. And as they accumulated energy by eating the plankton—this is sort of the way ecology worked—they would speed up, change colors, reproduce, and ultimately become large enough to prey on the other fish.
>
> Tony: Of course, you can see that the number of plankton is decreasing, so they are eating.
>
> Lawrence: If we leave `compost` on you can see there [are] regular additions of plankton.
>
> Tony: You see one just turned blue? We haven't yet taught the computer to make blue fish swim, so that's why it's not moving. We haven't gotten to that point yet. But now, that blue fish would be able, once we finish the program, to eat the green algae and the red fish.
>
> I'm having problems with making turtles interact with one another, at this point. Especially getting them to—we need them to multiply still. The algae have to be dividing and multiplying and growing so that you can make this an ecosystem that keeps running. We don't want this to have an endpoint where eventually there's just blue fish and no food left, and they are just swimming around doing nothing.
>
> So we need to have, basically, three things. We need growth incorporated into this, reproduction, and death. Once all those three aspects of an ecosystem are programmed into it, you should be able to run it,

and it'll just run. Then, you can hopefully change variables and see how that affects the overall system, but there should at least be a range where the system never crashes. (Challenge 5 pinup)

In addition to these two main threads of activity—the creation of the ecosystems model and the exploration of validity and experimentation—other groups were pursuing investigations that are tangentially relevant. Richard and Akira, an English teacher at a high school in Japan, began work on their own fishtank model. And Albert worked on a caveman model in which the cave men ate food and reproduced.

The prevalence of predator-prey type models occurs both because StarLogo is a good environment for building these kinds of models and because a number of members of this community have a personal interest in environmental systems.

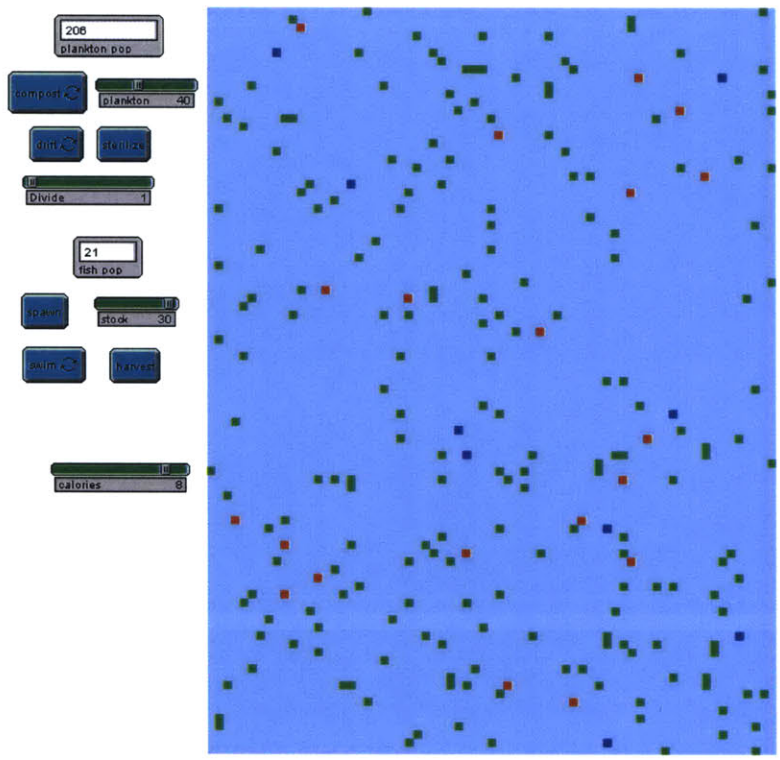


Figure 18: The first fishpond model, built by Lawrence and Tony for Challenge 5. The green squares are algae, the red squares are juvenile fish, and the blue squares are adult fish.

Refining Models

During Challenge 6, Cathy and Tony teamed-up to refine the ecosystems model that Tony and Lawrence began in Challenge 5. Based on her earlier experiences with Noah, Cathy explained that rather than simply add features to the model, they were working on improving the algorithm for algae growth:

> Cathy: Basically, we're working on Tony's pond example from earlier. What we're hoping to create is—we're working on something that has more of the elements of the ecosystem than had previously been included. One of the things we have been working on a lot, today, is trying to get the algae to reproduce at a rate proportional to the algae that's already there. So we want the algae to double when it reproduces. (Challenge 6 pinup)

Tony explained how their ecosystems model is similar to and differs from the Rabbits project (a predator-prey project that they explored earlier in the Workshop).

> Tony: I just want to mention this is basically a very simple ecosystem, a predator-prey type system. It's very similar to the rabbits, but it's different in a couple of ways. One way is that the reproduction here, when we do it this way—so that basically we're having all the algae make a copy of themselves—doing it that way, you end up with exponential growth, which is more realistic than what's in the rabbits simulation. Also, for reproduction of the fish, which we haven't really talked about at all. Our fish are red. They eat the algae, and they gain energy, and then they turn blue when they reach adulthood, and then they are

reproductive. And if they collide, they reproduce. So the rabbits just reach a certain energy level and then reproduce. In this model, they have to actually collide with another rabbit. Finally, we're working on incorporating a decomposition event, where the adult fish—both juvenile and adult fish will lose energy by moving, and if they lose enough energy to actually die, then they decompose, which basically you'll have dead fish on the screen, and then that will relate to the reproductive rate of the algae. So the more dead fish you have on the screen, the faster the algae are going to start dividing, so that you sort of have this very cyclical system that should run, you know, by itself. (Challenge 6 pinup)

In the final pinup, Cathy presented their latest version of the ecosystem:

> Cathy: This is a project... that's designed to simulate life in a fish pond. And within the pond there are green patches, which are algae. There are red fish, which are juvenile. And blue fish, which are adults... This is a model that [students] can tinker around with a little bit, set up the environment with different kinds of parameters and sort of see what happens.
>
> It starts off with all juvenile fish, which I haven't yet decided is a good thing instructionally or not.
>
> I ran this the other day for about an hour, and it didn't crash. But I have a graph that I hope I can locate. Okay this was a graph of... because it does take a long time to run. And one of the ways I would want to use this is to have students make some speculations about what they'll see in the population with different parameters and then watch it over time. And part of my responsibility—I'm a technology coordinator and a media research instructor at my school—is to help kids understand different displays of information. So, one of the goals that I would have with this is to have them generate different graphs. And they then can compare and contrast and draw some conclusions about what happened to their environment. So, in this one there were a lot of population oscillations. And this went for a very, very long time. Yes?
>
> Lawrence: Did you externally make any events happen, to make those oscillations happen, or is that just the natural cycle?
>
> Cathy: That's just the natural cycle of the population.
>
> Lawrence: Cool.
>
> Cathy: And there is also some randomness built into the system which I did so that students could say, 'well if I set up the parameters identically every time, am I always going to see the same behavior of the population?' [Another graph.] In this trial I had the algae reproducing at a much greater rate. And so it was doubling every, I don't know, like every two hundred turns of the—so you can see the population going up and up here. And this is just something that students could use to have a better understanding of how the dynamics were working, in whatever environment they created. So the graph of this one, right now, you can see it's not oscillating a whole lot. We've kind of gone up a little bit. And I don't know what's going to happen to it.
> (Final pinup)

Moving Beyond the Workshop

The ecosystems model did not end on the final day of the Workshop. As explored in Chapter 4, Tony (who was unable to attend the final pinup) and Cathy had an extended email exchange discussing how some of the decisions they had made about their model impacted the model's validity. And, Noah used the model in his Biology class, much as Cathy had proposed in the final pinup. Now, the model is up on the StarLogo website for use by others.

The pinups enabled the Workshop participants to share their ideas and projects at regular intervals. Much like conferences in a scientific community, these public presentations facilitate the exchange of existing ideas and often spark new ideas. They also provide a forum for the community to judge the work being done. During the summer Workshop, the community valued the ecosystems models highly (the audience was frequently excited about the latest ecosystems innovation), which likely increased teachers' motivation to continue working on those models. Again, the same types of interactions occur in research communities—the work that excites the community is likely to be followed up on.

Just as in a real scientific community, the relevance of all of the individual pieces of research was not immediately apparent to the teachers. For instance, Noah and Cathy's discussion about experimentation was not initially connected to the ecosystems model. Instead, each group moved forward on certain projects, periodically exchanging information about their successes and difficulties, and as the process unfolded some of the pieces of knowledge were integrated into an ongoing project.

The final project benefited from the ideas and insights of many teachers. Unlike some of the other projects, it was sophisticated enough that it emerged from the Workshop to see continued use in classrooms and laboratories.

Sustaining the Community

During the Workshop, teachers from all different backgrounds came together and coalesced into a strong, prolific community of practice. Together they were able to build models, tackle touch issues, trouble programming glitches, and explore new ideas. Of course, the Workshop is only a small part of teachers' professional lives. We were interested to see, given the strength of their community over the summer, what would happen when teachers returned to their schools in the fall. In this section, we discuss the experience of the community over time and propose structures to help increase its longevity and usefulness for teachers when they are back at school.

At the summer Workshop, teachers learned to rely on each other and themselves as modeling "experts". Even though they were still in the midst of the learning process, they realized that all modelers are still learning and they began to trust their own judgment about the design and use of models. Of course, they would still consult with the Workshop facilitators on specific questions, and we often encouraged them to think about aspects of modeling and experimentation that they might not have already encountered. Even so, they were full participants in our modeling community.

After the Workshop, their perception of their own abilities, and that of their peers, quickly faded. Instead of asking questions of each other they contacted the facilitators directly with questions and comments.[15] We became the "gate-keepers" of communication in the community—a role we had not been required to play during the Workshop—even though the Workshop email list provided a venue for the teachers to communicate directly with one another.

In addition to a virtual halt in modeling-related discourse among the group, the teachers rarely drew upon models or other artifacts that had been created by other teachers. A large percentage (over three-quarters) of the teachers used their own models, or materials that we had created for

[15] Cathy and Tony's correspondence about realism in their ecosystems model was one notable exception to this pattern.

the Workshop, in their classes. Very few teachers (only 2 that we know of) have used materials built by other teachers. Teachers' reluctance to build on or use artifacts and ideas created by other teachers is not unique to this project (Stigler & Hiebert, 1999) but is disappointing as it means that the very gains realized by the teachers as their group constructed models like the ecosystems models are not easily achieved when teachers are in school. It is as though teachers shed their perceived ability to judge the worth of materials that are not either their own or sanctioned by some external body (like a publishing company or university) and therefore are unwilling to integrate those materials into their courses. Schools do not provide any means for overcoming these barriers. In fact, through their endorsement of particular texts, frameworks, and curriculum kits and implicit acceptance of teacher's own strategies, they make adopting community-sanctioned materials problematic.

A Community Reunion

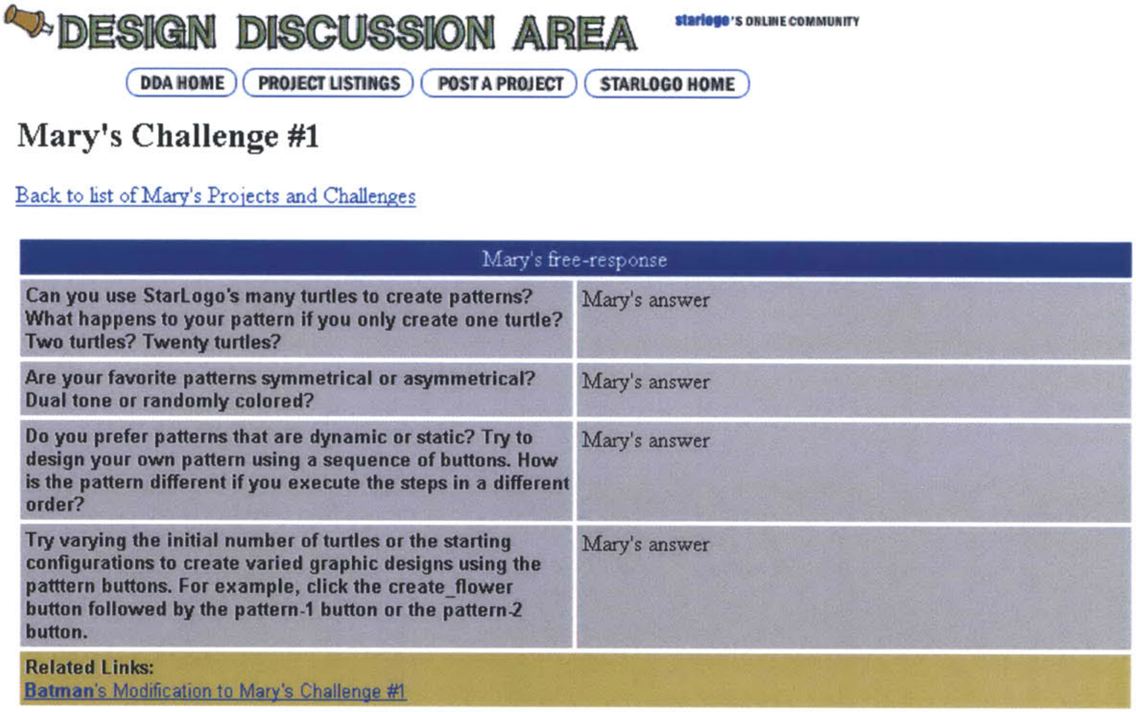
Since our virtual community, supported largely by email, did not seem to be adequately sustaining the social context we had created during the summer, we invited the teachers back for a reunion dinner. We also invited other teachers and researchers so that the teachers could describe their experiences over the summer and back in their classrooms. The teachers enjoyed reconnecting with their colleagues and wrote afterwards with their reactions:

> Terri (an elementary teacher at a suburban public school) Thank you for an interesting October 12th meeting. It was nice to hear all about the StarLogo projects, meet new people, and see friends. I'll be getting going with StarLogo as soon as the new computer lab is set up. I hope I don't have trouble loading the program on all the computers-if I do, "HELP!!!!!!!" (10/14/00 email communication)
>
> Bea: It was nice to see you all again—reminded me of how much I enjoyed doing StarLogo this summer. I'm glad you want to think about doing a simulation for birds Eat Worms.. The one part that I am stuck on is how to show the color angle—certain colors get picked up first but other colors are also picked up in lower numbers—how to show the camouflage factor while using the turtles that run around at random. I'm attaching some photos of the activity. (10/17/00 email communication)
>
> Sandra: Ditto on the evening; it was enjoyable and I think good to have a reunion. It reminded people of what they actually accomplished. (10/18/00 email communication)

Though the reunion dinner was a success on some level—it inspired some people to include modeling activities in their courses and provoked others to consider new modeling projects on their own—it did not jump start the virtual community. Soon, the email traffic on the list quieted again.

The Design Discussion Area

Given the short-lived results of the reunion dinner and the fact that many teachers require support as they try to implement new things, we pursued other avenues for sustaining a geographically diffuse community of practice. We surmised, given the experiences of the Workshop teachers and other members of the larger StarLogo users community, that email might not sufficiently support discourse around modeling, since there is no way to include a dynamic model in an email message. Thus, the discourse is necessarily separated from the subject of the conversation. In addition to modifying StarLogo so that projects can be saved directly onto a web page, we borrowed an online collaboration tool to create a community space that supports dialogue about model creation and exploration.



DESIGN DISCUSSION AREA starlogo's ONLINE COMMUNITY

DDA HOME | PROJECT LISTINGS | POST A PROJECT | STARLOGO HOME

Mary's Challenge #1

Back to list of Mary's Projects and Challenges

Mary's free-response	
Can you use StarLogo's many turtles to create patterns? What happens to your pattern if you only create one turtle? Two turtles? Twenty turtles?	Mary's answer
Are your favorite patterns symmetrical or asymmetrical? Dual tone or randomly colored?	Mary's answer
Do you prefer patterns that are dynamic or static? Try to design your own pattern using a sequence of buttons. How is the pattern different if you execute the steps in a different order?	Mary's answer
Try varying the initial number of turtles or the starting configurations to create varied graphic designs using the patttern buttons. For example, click the create_flower button followed by the pattern-1 button or the pattern-2 button.	Mary's answer
Related Links: Batman's Modification to Mary's Challenge #1	

Figure 19: The StarLogo DDA enables people to describe and upload their models and makes those models available for comment and use by other members of the community.

We designed the StarLogo Design Discussion Area (DDA),[16] which is based directly on the work of Janet Kolodner and her colleagues at Georgia Tech (Kolodner & Nagel, 1999; Puntambekar & Kolodner, 1998), to fill this role. Their online resource provides a structure for people to record their ideas, share those ideas with others, and receive feedback on their original design efforts. The original DDA has been adapted for the StarLogo Adventures Challenges. The StarLogo DDA contains a virtual "pinup" space with specific questions for each Challenge. Model builders post their solutions to a Challenge and answer the related pinup questions (see Figure 19). Then, other members of the community can post reactions to the original solution, and they can download the model itself and repost their own modifications with their own responses to the pinup questions. Teachers can use the DDA to facilitate discussions (or more formal pinups) and presentations in their classes or to collaborate with model builders in another class or in another country. It can also be used as a repository for modeling work and related discussions.

The StarLogo DDA will soon be released to the public, in conjunction with the publication of the *Adventures in Modeling* book (Colella et al., 2001). It is our hope that this resource will enable teachers to transform their ideas and successes from local discoveries (in their school or local community) to discoveries that have currency in the larger educational community (Latour, 1987). As in a scientific community, we hope that the combination of local results and community-wide interactions will lead to sustained changes in practice.

[16] http://education.mit.edu/starlogo/dda

A Pause for Reflection

Over the course of the Adventures in Modeling Project, we have learned several things about structuring teachers' experiences that have enabled us to help teachers enter a modeling culture. In particular, we focus on developing teachers' abilities to design, create, and explore their own models, we employ models in a variety of media, and we facilitate the development of a community of modelers. These aspects, both material and pedagogical, support the development of a modeling culture among teachers. Teachers learn about, gain fluency with, and investigate problems using modeling technologies. By creating a collaborative modeling culture among teachers, we enable non-scientists to frame, investigate, and better understand meaningful problems. Teachers develop the ability to construct models that are based on a certain set of assumptions, explore and investigate the behavior of those models, revise their understandings (and modify their models), and discuss and reflect upon their evolving ideas.

By the close of the Workshop, teachers are able to think about the world through a modeling lens. Sandra explains during the final pinup:

> Sandra: Okay, well I realize that I've been telling people that this [Workshop] has completely rewired my brain, because I started out being a random science teacher and now I'm a sequential StarLogo person. I realized this when I put this shirt on this morning. And I was looking at the design, and I said, well let's see most of these are patches, but the turtles would be the water wheel, the crowds, the person down here, and the car. I don't know—this could be the point of no return. (Final pinup)

Their experiences in the Workshop give teachers an additional set of tools that helps them think about patterns and processes in the world in new ways. The teachers have become members of a community of practice that uses models as tools to experiment with systems, explore outcomes, test predictions, and improve understandings—in short, they are able to use models to accomplish tasks of interest to them.

We find that teachers who are most comfortable challenging their own conceptions and intuitions are most likely to be successful in our Workshops. Teachers who are unwilling to question their existing understandings are rarely able to generate new ones. Like students whose misconceptions are never debunked (diSessa, 1988; Smith, diSessa, & Roschelle, 1993), these teachers are unable or unwilling to dislodge their prevailing mindsets to consider a new path toward thinking about patterns and processes.

The variety of types of models that teachers have experienced—from StarLogo projects to immersive Activities—help to solidify their understanding of modeling and give them a new appreciation for the role that personal experience can play in learning, even learning science and mathematics. Our multiplicity of approaches to modeling also gives teachers a foothold as they begin to consider how to bring aspects of their newly formed knowledge into their classrooms.

7. Transforming Practice

In this chapter, we highlight four paths to using new tools and ideas in the classroom. These examples are not meant to dictate the only four ways to implement modeling strategies from our Workshops. Instead, they are meant to capture the variety of ways that teachers go about changing their own practice, by painting a detailed, rich picture of four teachers' experiences. We are concerned not only with the kinds of changes that teachers make and how they make them, but also with the reasons they decide to change. Student learning and achievement is only one source of influence over teachers. Administrative issues, parental desires, accountability to state and national standards, and logistical issues at school all contribute to teachers' willingness and ability to alter their practice.

The Adventures in Modeling Project is primarily interested in how the understanding of new tools influences teacher thought and practice and secondarily interested in encouraging teachers (and their students) to design and build their own models in StarLogo. Because of this stance, we aimed to provide many avenues for teachers to choose from as they modify their practices. The case studies illustrate the overall integration of modeling ideas into classes as well as specific uses of StarLogo, Activities, and Participatory Simulations. They also highlight the ways in which teachers' choices to integrate these materials impact their professional practices.

In this chapter, we look at teachers' perceptions of their own working conditions that are likely to influence their decisions to change. First, we explore the issues that teachers report as impediments to changing their practice. Then, we describe how four teachers modified their courses, and their conceptions of their professional roles, through the use of modeling tools and ideas.

Barriers to Change

Before delving into the ways that teachers do alter their practices, it is important to address the issue that, in many ways, change is not easy for teachers. In fact, changing the practice of secondary school teachers has proved to be one of the most difficult areas of education reform (Cuban, 1993; Tyack & Cuban, 1995) (see also Chapter 2). These teachers can be especially resistant to change in part because their students face an increasing number of standardized assessments that test factual knowledge and recall, burdening their courses with more extensive curricular requirements and more structure than those in the early grades. Also, high school teachers tend to be more isolated in departments and less able to collaborate with colleagues, reducing their opportunities to participate in communities that might support change. Finally, some teachers are either content with their current practice or so overwhelmed by the complications and challenges of changing that they do not truly consider the idea.

But, even teachers who are excited about new technologies or ideas can have difficulties bringing those technologies and ideas into their classrooms. There is an extensive body of research that documents the general reasons that many teachers are resistant to changing their practice (e.g., Brown et al., 1989; Coppola, 2000; Cuban, 1986; Cuban, 1993; Elmore, 1996; Elmore et al., 1996; Tyack & Cuban, 1995). Here, we document three categories of resistance that our Workshop teachers verbalize most frequently:

- the limited amount of time they have to plan for and integrate new materials or methods,
- the challenges presented by unsupportive administrations, and
- the logistical issues of getting access to working technology in school.

We are not suggesting that these are the only barriers to bringing new tools and new ways of thinking, learning, and teaching into the classroom. Rather, we seek to highlight these three particular issues because they are the issues that are foremost in teachers' minds as they contemplate bringing modeling into their courses.

Perhaps not surprisingly, we found teachers much more likely to report external reasons why it was difficult to teach with technology. Only one of our Workshop participants indicated that personal lack of preparation was a factor in her decision about whether or not to integrate new tools into her practice,

> Sandra: I love the concept; I am just a little timid about the programming aspect and the time involved. (Reunion)

even though many indicated some trepidation about technology before using it in the Workshop (see Chapter 3). Clearly, the lack of teacher preparation is a significant hurdle impeding the introduction of new tools and ideas into the classroom—and, by choosing to attend the two-week Workshop, our teachers were implicitly requesting to become more prepared. Yet, a majority was still unwilling to publicly suggest that one component of improving their own practice was improving their own skills and knowledge.

Teachers' unwillingness to acknowledge gaps in preparedness to teach with and about technological tools stands in sharp contrast to employees' approaches to new technologies in other industries, where the assumption is that new technologies necessitate new kinds of training for employees. The lack of a community-endorsed structure for ongoing improvement as a component of teaching (except as indicative of a teacher's deficiency) reinforces the notion that improving one's own skills and knowledge is a welcome "extra-curricular" activity, but not something that good teachers need to do (Stigler & Hiebert, 1999). Even in places where professional development time is mandated, it is often viewed as time served rather than a serious opportunity to develop new skills and gain important knowledge.[17] In our Workshops, learning new skills was often accompanied by nervous laughter, as though learning was something to be embarrassed about.[18] We found that the teachers who were least willing to face their own lack of preparation were often the least able to put their arms around the ideas and tools in the Workshop.

The teachers in the Adventures in Modeling Workshop represent a fairly typical cross-section of teachers (see Chapter 3). They are interested in exploring technology, the new ideas it can help them think about, and the ways that it might improve teaching and learning in their classes, but many are not, or at least they don't think of themselves as, pioneers of massive curricular modifications. Reflecting on a piece by Chris Dede, Bea expressed a common sentiment:

---

[17] 2/9/01 personal communication, Cathy.
[18] e.g., Challenge 3 pinup and Pixelated Paths discussion.

> I read this before the Workshop. I especially liked the parts about bottom-up change and "settlers." I like change but do not want to/cannot put forth "heroic efforts" on an everyday basis. (8/1/00 email communication)

> Chris Dede on how Technology Changes the Role of the Teacher[19]
> Thus far, most educators who use technology to implement the alternative types of pedagogy and curriculum are "pioneers": people who see continuous change and growth as an integral part of their profession and who are willing to swim against the tide of conventional operating procedures - often at considerable personal cost. However, to achieve large-scale shifts in standard educational practices, many more teachers must alter their pedagogical approaches; and schools' management, institutional structure, and relationship to the community must change in fundamental ways. This requires that "settlers" (people who appreciate stability and do not want heroic efforts to become an everyday requirement) must be convinced to make the leap to a different mode of professional activity - with the understanding that, once they have mastered these new approaches, their daily work will be sustainable without extraordinary exertion. How can a critical mass of educators in a district be induced simultaneously to make such a shift?... The driver for bottom-up innovation in a district is the children. Educators can draw enormous strength and purpose from watching the eager response of their students to classroom situations that use alternative forms of pedagogy. The professional commitment that kids' enthusiasm can re-inspire is a powerful driver of bottom-up change.

Our Adventures Workshop, and the subsequent changes that teachers made in their classes, are important for the research community because we did not target or cater to technological pioneers. Our teachers were quite mainstream both in their existing use of technology and their desire for more integration than they currently have. While we certainly had exceptions on both ends of the spectrum, many were "settlers". They want to improve their knowledge of technology and enhance their teaching but are unwilling to take high risks to do it.

Limited Time

The Adventures in Modeling Workshops encourage a deep investigation of material over time. Whether teachers are building models for use by their students or engaging their students in an Activity, the approach we advocate takes time. The benefits of this approach can be worthwhile—teachers and students engage in thoughtful analyses and develop rich understandings of topics that interest them. Yet, time is a limited resource for teachers, both in terms of the number of hours they are able to allocate to work outside of the classroom and in terms of the amount of time they are willing to devote to any single topic in the classroom. In addition, the introduction of new standardized tests and the reliance on proscribed curricula leave little class time for inserting other ideas. Each of these factors constrains the changes that teachers are willing and able to make to their curricula.

Teachers perceive their own professional time as extremely limited. This deep-seeded perception influences the amount of time they devote to their profession and the ways in which they choose to spend that time. Both classroom teachers and technology specialists find very little time to spend on curricular development. This lack of time profoundly influences the amount and depth of change that teachers enact.

> Max: I had a great experience in the seminar over the summer. I felt like I learned a lot about [modeling]. I left the summer feeling very excited with an armload of materials, CDs, and certificates, and all kinds of stuff. I have not done anything with it since, except it's a nice pile of stuff in the corner that I look at every

[19] http://millennium.aed.org/dede.shtml

> once in a while. Mainly, because I just started a new job in the school. And, also one of my responsibilities is that I am the technology curriculum coordinator at the school. The school has just moved to a new location, so I have been working mostly in infrastructure things—installing new computers, hooking them up to the network, installing mail software, and so on. And just becoming acquainted with the curriculum—it has not given me a chance to think about how StarLogo will be woven in the curriculum this year. (Reunion)

Teachers are increasingly under pressure to teach a large body of content in a limited amount of time. Generally, this pressure is attributed to the move towards stricter standards and accountability measures (McNeil, 2000). This predicament is especially troublesome at the high school level but increasingly extends to the middle school level as well. The pressure to cover a large body of content is the biggest barrier cited by teachers to changing their practice.

> Julie: And I mean, I'll be honest, I have problem with the time commitment that it would take to teach these kids how to do [modeling]. I—you know, honestly with all this stuff—we have a colleague at our school who's line is 'If you'd like me to put that on my plate, what would you like me to take off in it's place?' That's sort of how we are all jammed with curriculum is if I want to put something that's going to take a week or two in, I'm going to have to take two weeks out of something else, and that's the tradeoff. So, I can't see—I can honestly say, I probably don't see myself teaching them modeling, but [I can see] using the games and using a model that's been developed to tie it all together. But what I can see in my school is more like in the tech class is learning StarLogo. (Workshop discussion)

With the rapidly rising stakes of testing and the pressure to conform to the standards, many teachers fear that they do not have the luxury of introducing new topics into their courses, even if they feel that those topics would be beneficial to the students.

> Tony: I mean, one problem I can envision with teaching 7th and 8th graders, I mean, I think it would be really worthwhile to have them be able to learn how to write their own code in StarLogo, but it's going to take, I think, a lot of time. You know, I think if they're capable of learning a language, if they can learn Spanish, they can learn to write in StarLogo. But it's going to take a lot of time, and there's a lot of pressure to teach what is covered in the standards, the state standards.
>
> And, you know, sure if you have a good model of something, you know, and the kids can manipulate variables and see how that changes, you can teach content that way. But in terms of teaching kids to create their own models in StarLogo, how does that translate to the standards? I mean, how are you going to sell this to your education team, your colleagues and your principal or headmaster? How are you going to convince everybody that this is worth spending so much class time on? (Workshop discussion)

Teachers in the lower grades are, in some states, more immune to this predicament:

> Liz: I use it a lot. I teach 6th grade, and I use Microworlds and Lego/Logo. I teach it in math, and the reason why I teach it in math is for problem solving. And it's an incredible tool. The other thing I have found is that kids, most kids don't understand what a computer does. They know they put the CD in, they press one or whatever it is that causes it to go, and it does what's on the CD. They have no idea of the power of computer. And I had a kid two years ago (we were just doing Lego/Logo) and we still have to, we had to walk the whole program through, and [he] realized that we were writing a procedure and that procedure could change however we wanted to change it. He raised his hand and he said, 'You mean that means I can tell this computer to do anything I want it to do, and it's going to do?' And I said, 'That's right.' And it was like an epiphany for him. He was just incredibly amazed that this was true. (Workshop discussion)

And in the younger grades, teachers are slightly more optimistic about how modeling activities like the ones we engaged them in during the Workshop can help students achieve the goals set by the standards:

> Bea: Some people said that the kids [at my school] were asked to set up an experiment on the MCAS [a state test] and they couldn't do that. At my school the kids were totally at a loss, so they needed me to fill in those kinds of skills.
>
> But I'm real sympathetic to the content people. I mean, I understand, you know, the gun that you're under, yeah. In our schools the 6th grade science is sort of like 'do as many standards as you can' or 'do as many chapters as you can' and no one really cares and you're not really held accountable. So, that gives me a lot of freedom that, you know, I just think you don't have. (Workshop discussion)

Teachers whose students (and who themselves) will be held accountable by high-stakes tests require more convincing before changing their practices. Tony reiterates his question:

> Tony: So, I don't question the value [of modeling], but my question is, 'is his MCAS score going to go up?'
>
> Liz: Right. But even in science, if they have to build, if they have to construct the model they have to know certain things about how that system works.
>
> Tony: Right. (Workshop discussion)

Liz, the 6th grade teacher, is still talking about the higher-level skills that the students will acquire through modeling. Though Tony and others agree with her assessment, it does not fully address their concerns:

> Sandra: But Tony's point is well taken that there—I mean I—
>
> Tony: If anything I think the standards—the standards should be modified and, you know, to reflect the need to teach these skills.
>
> Sandra: I mean it's—there's a big push in our (well, I'm sure there's a big push everywhere) to integrate technology into the everyday work of the curriculum. The problem is there's so much curriculum to cover that we no longer have the luxury of doing this. You can't spend the amount of time necessary that you have to teach the kids how to do programming. Maybe if you do want—and the amount of time it takes to design is my concern also. It's a long time invested. (Workshop discussion)

Here, Sandra articulates both issues. She doesn't feel that she has enough time in the classroom to teach her students how to program, and she is concerned about the amount of preparation or "design" time that it will take her to integrate modeling into her existing lessons.

Though technology specialists and computer teachers feel equally pressured for time, many classroom teachers and administrators see those courses as logical places to fit in these new ideas.

> Julie: But what I can see in my school is more like in the tech class is learning StarLogo. (Workshop discussion)

> George (an administrator): Well, I think that if you don't have the classroom time to integrate StarLogo in the curriculum, you either can think about starting computer clubs in the school or if you already have a computer club, go to the person that runs the computer club and suggest that they maybe incorporate StarLogo. I mean, I think if they get turned on to it, they're going to think it's pretty neat and they might want to use it. I know it means time and probably you won't get reimbursed for it immediately, but I think that the rewards probably… (Workshop discussion)

For an administrator, an after-school club is a perfect place to incorporate new ideas, like modeling, and new tools, like StarLogo. Of course, the teachers already feel pressured for time—not just in their classes, which George was addressing here, but also in their whole professional lives, which would be made only more full by the additional (un-paid) responsibility of running and after-school club. While some teachers, like Carl who is profiled later, do start these clubs, they generally need other release time or perks if it is to be a sustainable situation over the long term.

Finally, there are a few teachers who are really on a mission—Chris Dede's pioneers. While not all of these people are early adopters of technology per se, they are willing to really commit themselves to making changes in the ways they educate their students, even if those changes are difficult to implement. Noah, also profiled later, describes part of his rationale for his high-level of commitment to teaching modeling to his students. He discusses two articles, one in the New York Times and one in the New England Journal of Medicine, about the promise of genetic research for curing diseases. While the NEJM article focused on the importance contribution of environmental factors in the onset of cancer, the NYT article points out that environment alone is insufficient to explain the causes of cancer.

> Noah: I sort of feel on a mission. We don't teach interactive kinds of thinking, and so—and there's this thing that I saw in yesterday's New York Times that really got me. OK, nature versus nurture is a science issue, right? So, [take] the human genome project [for example]. Scientists say 'the genes—we're going to find about these genes and everything about us is going to be solved now that we know all about these genes.'
>
> OK, then the next week [there is a] New England Journal of Medicine [article on a] twin study [in] Scandinavia [that] shows that heredity has almost nothing to do with cancer. You know, so now we have 'everything in a gene' and 'nothing in a gene.'
>
> And then the author of this piece [holding the NYT] says, 'What was missing from the Scandinavian study was the analysis of the dynamic and the intimate interaction that occurs between our genes and the world around us.'
>
> People don't think like that. We don't—you know, it's not even in their awareness. So, what we do with this is we go and we show the students this kind of thinking, and so then when they get to be scientists and physicians and whatever they get to be they've at least had the experience. They're used to a right answer. (Workshop discussion)

Provoking students to think about interactions is one of Noah's goals. In his analysis, it doesn't really matter what the specific content is, as long as it encourages students to consider the impact that interactions have on patterns and processes in the world around them. He describes how he would use the Tortoise and the Hare project[20] to teach a valuable kind of experimental thinking.

> Noah: You know, I'd take that Tortoise and the Hare [model]. And I don't care what you teach. You take that Tortoise and the Hare [model] and you say to the kids, 'Give me a condition where the hare wins.' You say, 'Give me a condition where the tortoise wins.' And they're all going to come at you with different answers, and you can say, 'Wow, that's really cool.' Now 'give me a condition where it's impossible for the tortoise to win.' 'Give me a condition where it's impossible for the hare to win.' And they'll think they got it. So they all come up again with all different possibilities. And then you say run it 100 times and then all of a sudden what they thought was absolutely true on all circumstances isn't true any more because the pond comes up in front of the hare and on the 97th time it doesn't work.
>
> You're just teaching invaluable outlook in the world. So, I love everything that's going on. I mean, I think they're fantastic because, you know, because you can see it, you know, you can see it and allows you to do an [experiment], and so it's just great.
>
> You know what—I think you have to have—you just, you know, if you believe it's important then you do it. And the other thing is that there is that investment in thinking—an investment in thinking skills. You know, Albert was talking about, you invest, you teach a freshman a little bit of this, little bit of this, and then you end up doing differential equations with your senior you could never have done before. (Workshop discussion)

Noah enthusiastically supports teaching his students valuable thinking skills. In many ways, he is the kind of pioneer to whom Dede referred. He is willing to go to quite extraordinary measures to integrate new ideas that he feels will improve his practice. But, like real pioneers, educational pioneers often run into unbelievable resistance at their schools.

Insufficient Support

Whether teachers are pioneers or not, it can be very difficult for them to get support from their superiors for the changes that they want to make; however, our Workshop participants exhibit a remarkable resilience about this type of challenge. Many of them put up with a surprising level of interference and opposition from others.

Teachers during the summer spoke about their expectations if they were to change their classroom practices:

> Bea: I think that my experience with computers is you do have to anticipate that you're going to get negative feedback. You know, this goes back 10 or 15 years ago just doing these great MECC programs and these simulations on the Apple II that at that time were really good. But in that whole program, I was the only science teacher who was taking the kids in there and, you know, just really learning a lot and having a great time and kids get turned on. Then I get called into the principal's office and blasted out, 'Now, what are spending so much time in the computer room for? It looks like the kids are just having fun and games.' You know, I mean this really happened. And you know my department chairman was down on me then.
>
> And then about 5 years ago I did an Internet project, you know, back when this—nobody in our school was even using the Internet. We just got a—we did this great project. It was a newsletter project. You went on the Internet, you found all this endangered animal information, typed it up in a two-page newsletter

[20] Based on Aesop's fable. A tortoise and a hare race down a path. The tortoise keeps a steady pace, which the user can set, while the hare races ahead and pauses at various points, based on his level of "laziness" (another user-controlled parameter).

format—you know, and I'm bragging, but the kids really did it great. It came out great. It was a really great project.

Then I got the feedback on that in my evaluation. They said, 'Ms. Flanigan appears to have good word processing skills which she seems to be able to impart to her students.' And then my department chairman said, 'You know, you should be doing more hands-on,' meaning the traditional science experiments.

So, you know, go for it and do it. Just be prepared for that negative. That's going to happen, and I'll bet you $100. It doesn't sound so optimistic, you know, you'll get put down for it some way. You won't—you think they're going to say, 'Gee, isn't this wonderful that you're doing all this stuff.' Instead you don't—you get the negative. (Workshop discussion)

The resignation to a lack of support from superiors is a shared, widely held belief.

Noah: You know what it is, there's a lag time [until things become a regular part of the curriculum] and there's that negativity. Yeah. I was dying, I was dying here behind you. You think people are going to say, 'You're doing such a great job.' [laughter] You think you're going to get called in and be congratulated and you get hauled in on the carpet. (Workshop discussion)

Surprisingly, these harsh realities do not stop teachers from considering implementing change. When the same teachers talk about their expectations of what the kids might accomplish, they are very enthusiastic:

Bea: I'm trying to say so that that's where it all goes so that you just—you can start it and then you see where it goes. So, yeah, I'm enthusiastic. I'm looking forward to it. (Workshop discussion)

And many of them continue to be enthusiastic through the school year, applying for grants to use StarLogo in their classes and persevering even the face of rejection from peers and administrators.

Teachers prepare for this lack of support in different ways. Some become very enthusiastic, some marshal support from other people, and some turn to research for validation. Ivan holds a masters degree from Harvard, yet still felt the need to "back himself up" before introducing new tools in his class:

Ivan: I just want to talk about higher-level thinking and lower-level thinking [and] something I experienced last year. I was student teaching a geometry class, and I wanted to use [Geometer's] Sketchpad in the class. I was in a really competitive environment, a very competitive school and town. And before doing Sketchpad activities, what I wanted to do was somehow back myself up and find out well, you know, the parents in this town are really concerned about MCAS, they're concerned about SATs, they're concerned about the kids getting into schools. So, what I wanted to see was the effect of using—classrooms that used something that fosters higher-level thinking. Like Sketchpad or Supposer fosters higher-level thinking because [they] make you conjecture.

So, I looked at the research, at the educational research, and what I found was through numerous studies... that classrooms that had a traditional curriculum in conjunction with some type of work that fosters higher-level thinking tend to score higher on a lower-level test than classrooms that concentrate just on lower-level type work.

> I think the beauty of StarLogo is that it does foster higher-level thinking, and even though it doesn't foster the kind of thinking that you're tested on through the MCAS or SATs, I think that if you do use this in a classroom that you are, and the educational research does show, that... you are going to get higher test scores on the lower-level tests. So, that was something I pursued last year because, I mean, I wanted to kind of back myself before I started doing something in class. (Workshop discussion)

Whether they are concerned about the reactions of parents, other teachers, or administrators, many teachers do not work in a system where they are fully empowered to make pedagogical decisions about their courses. This situation points to a conundrum in our educational system—it embraces local control of schools and asks individual teachers to improve their practices, yet does not give them a structure that supports improvement without shame nor does it entrust them with the power to make decisions about their craft.

Lack of Access to Technology

The issues surrounding the use of new technologies include access *to* working computers and access *on* those computers. Most of the teachers we worked with don't have computers in their classrooms, so they use the computer lab. However, many of them don't have the privileges to install software on those lab machines. This problem can be quite a hurdle when trying to integrate tools that are not universally used, like StarLogo.

Again, teachers' refrains are quite consistent, and their willingness to persevere in the face of difficulty is notable. When we asked about visiting teachers' classes, many responded quite cheerfully about the logistical issues in their schools:

> Will 9/11 So far everything is going great. I do plan on using some of the simulations I wrote this summer. Right now I am just concentrating on learning my way around. The only problem is that the computers I have access to are in another room, so we have to room swap to use them. But I will prevail eventually.
>
> Julie: I teach 7th grade science. I was in the summer Workshop and I have yet to use it because we are in the midst of a two-year addition/renovation project, which has caused some difficulties with our computers in terms of accessing the computer lab to have someone teaching. We are looking at about a month down the road. I am not even into the unit yet that I would be using it in, so we'll just have to push it back by about a month. (Reunion)

Just getting access to computers is still a problem in many schools. During the reunion dinner, the teachers swapped war stories:

> Terri: I teach fourth grade. Last year with my class I dabbled in basically just using commands and exploring on their own. We made designs and some of the other students copied their designs. This year I have not done much at all because all the computers in my room were somehow, I don't know if they were destroyed or I don't know what happened to them over the summer, but I have not done anything this year. We are getting a new computer lab, supposedly [in] October, 2000. I have the tables all cleared for them! When that happens, I will begin.
>
> Bea: Did they just stop working? Did they just go dead?
>
> Terri: No, what happened is my hub—I had set up my own little network in my classroom and over the summer the hub was, I don't know what. I think they trashed it or something because it disappeared. I just got another one. Because, this isn't stuff that the school buys me. I have to scrounge around for it and get the wires myself and the kids even help splice them together—it's unbelievable what [4th graders can] do to get the computers working. They set up their own little network in the room with old computers that I pick up from businesses that throw them away. (Reunion)

In several schools, teachers had difficulties getting new software onto their computers. Terri's experience is typical:

> Terri: I talked to [our] technology director again today about if I could download StarLogo onto the computers in the lab. Her first words were 'I know Logo, and I'm not a big proponent of it'. Can I give her your e-mail address? I think she said she would like to talk to you. I'm giving her the information on the download. If I don't get a yes soon, I'll write to the Assistant Superintendent of Curriculum. (11/15/00 email communication)

For teachers to change the ways that they teach, they need reasonable, reliable access to new tools. For many teachers, just getting their students into the computer lab is difficult. It is important to keep in mind that these conditions exist even though the percentage of wired classrooms is increasing. Not all of those wires are functional all of the time.

Many Paths Toward a Modeling Culture

During the Workshops, and in the previous chapters, we focused on teacher change. Could we change the ways that teachers approach problems, learn about new topics, and present their findings to peers? In this section, we shift our focus to exploring how teachers are able to integrate some of those changes into their professional practices.

In spite of the significant challenges, many teachers strive to alter their practices. Of the teachers in the summer Workshop, over three-quarters made changes (that we know of) in their courses. In this section we describe four case studies that illustrate various paths to integrating new ideas and tools into existing practices. We explore issues including how and why teachers decide to include modeling tools and ideas in their classes, how teachers refine their practices in light of new understandings, how their existing conceptions of teaching influence the aspects of modeling they appropriate, and how the structure of their work environments constrains or enables change.

While not all teachers from the StarLogo Workshops succeed in changing their practices, this chapter shows that there is a high degree of variability in teacher adoption of new technologies and new ideas. One of the strengths of the Adventures in Modeling project is the conscious decision to validate and support many pathways to change. This stance has allowed teachers to appropriate the facets of modeling, both on and off the computer, that work best for them in their classrooms. In this way, the changes that these teachers undertake represent solutions to their perceived classroom challenges. Our open-mindedness regarding this range of outcomes has increased teachers' willingness and ability to undertake change.

Path 1: Noah

Noah teaches Biology to grades 9 through 12 and has over 20 years of teaching experience. A former scientist who left research because he "always wanted to teach," Noah is extremely committed to all aspects of his students' development. He wants to alter their views of science, and their views of the world. That said, he is in many ways a quite traditional teacher at a traditional boarding school.

Noah is overwhelmingly concerned with his students' development as people. Though he teaches science, he frequently slips material that he thinks is important for his students' general intellectual and moral development into the curriculum. Noah's desire to include modeling in his class grew out of a personal intellectual connection to the material that intensified during the Workshop and some limited classroom experience using models.[21] He is enthusiastic about approaches that enable one to see the world in new ways. The modeling approach aligned well with his desires to impart to his students the role that engagement plays in learning and to teach them new tools for making sense of the world.

During the Workshop he strongly connected to the idea that all kinds of models can be 'tools to think with'. He saw modeling as a tool that could change how his students think about and understand science. He felt it important to use modeling, especially StarLogo models, throughout the year so that it would be "just another tool" for his students. He tightly integrated modeling with content in his courses from the beginning of the semester, even working it into his assessments. Yet, often, especially when not working on models, he fell back on more traditional, didactic teaching methods.

Throughout the year, he explained his classroom activities and the rationale behind them to his administration. Despite these consistent efforts and their early endorsement of his choices, eventually he discovered their displeasure with his efforts to integrate modeling ideas in his classes.

Several threads are significant in Noah's story:

- He is committed to influencing how his students experience science and life.
- He became intellectually enamored with modeling.
- He included modeling in assessments.
- He sought, but did not gain, his administrations' approval.

Noah's Role as an Educator

During the October reunion, Noah explained his rationale for including modeling in his courses:

> Noah: I incorporated some of these models into an ecology unit in a high school Biology course...
>
> I introduced this whole unit to the kids after they read about—the book didn't even deal with the equations for exponential growth because it is not quantitative biology. They had this really awkward formula G—R something. I took a quote from the Workshop—I am not sure that I got it exactly right but, 'situations that are usually described by complex mathematical relationships can be generated by a simple set of rules.' That is the way I went into it. These kids are bright, but they're not really quantitative so they were really happy that we were going to do this.
>
> That is how I introduced it. Then we did the physical models—the Penny Growth model, and we did the Paper Catchers model. We did a bunch of physical models...
>
> In order to model population growth, there [are] a bunch of things you can do. One is, you can do the pennies and have them multiply [on] every table. And, my colleague in the next room has this neat little lab that he does and it's a perfect way of doing it, 'cause it's a little petri dish with duckweed, which is a

[21] e.g., http://www.taumoda.com/web/PD/setup.html

plant that floats on the water, and you can put one little duckweed or you can put a bunch in just like the pennies, and then put some fertilizer in the water and then you can watch them reproduce.

So, you have the biological system, which is a model because it's not a real pond, and then you have the pennies, and then you can go to the computer model. So, then you have a laboratory model, a tactile model, and then you have a computer model, and they're all dealing with pretty much the same thing.

So, how this worked... We did the Penny model and then had a discussion and asked 'how is this real and how is it not real'. The kids said, 'It is like real because there is exponential growth but it is not like real because there is no death.' That is the end of the period—perfect timing!

Audience: [Laughter].

Figure 20: Noah and his students playing Paper Catchers.

Noah: Then on next day... we do this model (Paper Catchers) where if you catch the thing you can reproduce—you can call somebody else into the circle—but if you don't catch it you die. So we looked at a graph there, and we had death incorporated into that model and there is another computer model that has death incorporated that the kids can play with that and discover.

So, then we modeled population... Then we get into communities—there is a model with rabbits and grass where they try to stabilize the model. And now we start to get into some terminology. 'What does this slider represent?' 'What does grass growth rate represent?' 'What does hatch threshold represent?' Not really heavy on it, but just a little bit once in a while. Sort of teasing them to see the connections.

In working this, rather than playing one against the other—the textbook against experiences—I was playing one upon the other. It just would build; they would reinforce each other...

It was incredible because I started out the year with a poem called "Learning from the Trees." It is a great poem and it talks about how you learn about trees indoors from a book, which is a product of a tree. Then it describes all the language of the trees. It is a beautiful poem. And, then you go—armed with this knowledge—you go out into the world and... Then, you take this knowledge out and see how it works. One of the kids said, 'Oh, you mean just like the poem!' And he really came back to it. But what was cool was that the *model* was the real world. He was talking about not going out to the trees, but the model was the experience. It was really cool. It was very significant.

Now, we are at the point of wrapping it up and seeing if we can make this bridge—seeing if we can make this really tight learning experience that is meaningful and is not just intuitive and difficult to talk about and it's not just verbal, but the combination of the two. [Then] you have a real solid learning experience.

And I talk to kids about this all the time. I share a lot with them, my hopes and my dreams for them. I did not share this with them, but I will share it with you. One of the reasons why I wanted to do all this was because I wanted the students to have access to complex systems. To have young people having experiences and dealing with complex systems and getting into their way of thinking. And to help them see that maybe more than cause and effect and determinism explain certain events. That certain things are beyond cause and effect. Also, ultimately to see that cooperation as well as competition are driving forces in nature. I don't share that with them but those are my ulterior motives. (Reunion)

His excitement about modeling was a motivating factor as he worked to integrate modeling in his classes, in part because Noah is so committed to instilling a love of learning in his students.

> If I were one of the kids I'd be so tickled that this is going on. It is so exciting. (10/3/00 personal communication)

He wanted his students to develop in a multi-faceted way and to realize that learning can be very personal and very engaging. Sometimes, science is quite distant for his students. Noah likes models because they are concrete artifacts that his students can question, modify, and explore. These possibilities not only help the students understand the material better—they also help the students develop a positive stance toward learning.

> It's great for the kids because they see that what they said [their ideas and hypotheses] don't just go off into the air and disappear. They manifest themselves in the model where they can be explored. It's empowering. When you can't ask answerable questions it makes science seem very distant. (9/20/00 personal communication)

He wanted his students to be curious about their world. He viewed modeling as an avenue for developing that curiosity. When he used models in class, he enabled his students to manipulate systems and ask and investigate questions of interest to them. He wanted to integrate modeling throughout his teaching, in order to infuse the rest of his teaching with the same potential that he saw in modeling.

> [I want the kids to see] how you can take a textbook word and relate it to the models. Today was fantastic. They would have played with those models for 2 weeks. My objective is to get the kids hooked on those models. The other stuff [the textbook] is just an excuse. To do that kind of learning is the goal. (9/26/00 personal communication)

Yet, Noah is a traditional teacher and as soon as he veered away from the model he returns to his more traditional teaching techniques. Here, he was questioning his students about a predator-prey model in which rabbits eat grass, hoping that one of them would relate the grass growth to "carrying capacity", a vocabulary word in the textbook:

> What is the peak of the grass? [pause] In textbook terms what does that refer to? [pause] When the grass is at high rates it stands for what? [pause] A high blank? [pause] A high cc word? (9/26/00 personal communication)

Noah's pedagogical philosophy is at odds with his own skills as a practitioner. This kind of questioning was not representative of the kind of learning environment he wanted to create for his students. Yet, he did not have the teaching skills to facilitate a collaborative conversation or involve his students in other ways. Modeling was appealing to Noah not only an avenue for his student to learn new things, but also as an avenue for him to remake himself as a different kind of practitioner. Though he was not 100% consistent (sometimes falling back into old teaching patterns) the infusion of authentic scientific discovery changed the character of teaching and learning in his classes.

> Last week [modeling] was a lot of work but this week it's just there. It's just a part of the class. Posters are a way for us to see if the kids are really understanding as much as we think they are. (10/2/00 personal communication)

> Class went very well today. They are beginning to get comfortable with doing something difficult, which is really cool. As they folded up their tents for the day, I asked them to write themselves a note for Friday. They asked, 'Why?', and I realized that they may have never done experiments that extended over a period of several days. Experiencing this aspect of science in high school is unusual. (10/25/00 email communication)

As Noah embraced scientific modeling for himself, he was also able to bring the same ideas into his class.

Intellectual Growth through Modeling

Another appeal of modeling was that Noah approached the model construction and exploration process as a learner and a scientist. Modeling is intellectually stimulating for Noah. When he models, he takes off his "teacher hat" and returns to his role as scientist.

> I was thinking about the models—I mean, really thinking. Not as a teacher but as a scientist. (10/13/00 personal communication)

Throughout his use of modeling in his course, Noah used the models for himself, rather than only as a tool for his students. He used modeling as a way to confirm and test his own knowledge and satisfy his own intellectual curiosity:

> Models do illustrate genetic drift, but also evolution. Genetic drift is a change in allele frequency (which is evolution) due to chance alone. In the absence of mutation or gene flow in, genetic drift results in loss of genetic diversity. We saw that...so can the kids. (10/17/00 email communication)

> These models are fun! I enjoyed playing with them last night...so much so that I missed the first inning of the World Series. I copied model descriptions for kids and made up a work sheet. They are reading the first evolution chapter, which includes the concept of genetic drift. (10/25/00 email communication)

His willingness to challenge his own beliefs increased his ability to learn from models, which in turn reinforced his own excitement about them. Early in his classroom use of models, he devised an assignment for his students that asked them to use a model to produce a certain kind of behavior, but he had trouble tweaking the parameters of the model to elicit the behavior. He called one night to discuss the model, and talked about how much fun he was having working with the models.

> I worked so hard to avoid getting sucked into this, but I love it. I spent an embarrassing amount of time on [stabilizing this ecosystem model]. (9/25/00 personal communication)

Part of his excitement stemmed from being on the edge of what he knows—much like a scientist would be. Later in the year, he modified a complex model on his own:

> It was fun, but I have to admit, it was tense for me; but I feel proud now. (11/7/00 email communication)

With modeling, Noah threw himself into generating, evaluating, and refining knowledge. Instead of merely asking his students questions about words in the textbook, he brought an atmosphere of scientific discovery into his classes. Modeling put him in the role of a learner and discoverer, which changed the way that he approached teaching his students and influenced the way his students thought about learning.

Though I haven't used models for some time, the atmosphere of discovery and teacher as co-learner remains [in my classes even] as we do more traditional material. (3/1/01 email communication)

Assessment

As intent as Noah was on bringing new and innovative topics and techniques into class, he was also aware of the need to keep things like "regular" school.

> The different stuff was great. It wasn't threatening. No, 'what do I have to know for the test?' That's a big issue, a big factor. The fact that it didn't happen is very positive. The posters for parents' day are great. They keep it school like—there is a lab report for this lab. And it has a real product, which is great. (9/26/00 personal communication)

> The coolest thing curriculum-wise was they've been looking at these pyramids [which show a small number of predators at the top and the correspondingly larger number of prey necessary to sustain the predator population at the bottom]. Probably next year I'd put in a more analytical component. I'd have them look at the ratio between producers and consumers. I like the fact that they have a lot of freedom. It can't be too school-like, but it has to be enough [like school] that they still believe in it. (10/10/00 personal communication)

An important part of regular school, for him, his administration, and the students, is assessment. Because he was so intent on integrating modeling ideas throughout his curriculum, he was especially interested in making sure that he was assessing his students appropriately.

> [I am very interested in] carrying things through to assessment. That doesn't often happen with educational innovations. [Typically you see] no assessment or a half thought out one or an old-style assessment that doesn't really measure what you did. (10/3/00 personal communication)

> That's one of the things I feel really good about—making non-school things into school. Taking things that are playful and creative and making them real for the kids—real in the sense that they have consequences, i.e. assessment. 'Cause this is a traditional school in terms of classes and tests and stuff. (10/10/00 personal communication)

Like many teachers, he used the process of creating assessment instruments to refine his own teaching strategies.[22] Building a test for the ecology unit spurred him to contemplate how he could reorganize his course to make better connections between genetics and evolution.

> Wow! I will discipline myself and not look at the models now, as I have tests to make up. I will give the biobuddies [accelerated biology students] a 75-question short response test on Friday and assess their skills with models on Monday. For the Monday practical they will make some changes to a stabilized model, report and explain the results using ecological principles. I will also develop a task for them on a model that they haven't yet seen. Short answer stuff is about done. Will work on the other tomorrow. Since we have the evolution models (almost) I will consider backing into genetics through evolution. A fascinating idea. (10/17/00 email communication)

Students' successes with Noah's new assessments confirmed his belief that modeling was enabling them to build deeper understandings of scientific issues.

---

[22] In fact, Noah created a number of new assessment instruments to better understand the impact of modeling on his students' understandings. Among other things, he asked his students to create authentic displays for a "modeling museum" and to go to the computers, run models, and observe and document particular behaviors during the exams.

> It all happened. They did very well on the short answer. In the model test, there were some rough spots—some wording I didn't get quite right—but they really got it. The beginning was tough but then they were really cranking through it by the end. (10/24/00 personal communication)

Administrative Issues

Though his independent school lacks some of the constraints of public schools, Noah has been burned in the past by integrating new ideas into his classes without keeping the administration informed.

> This year I did everything right. I asked if you could come [to visit the school] and if I could do the modeling museum. Because last year I got in trouble. I moved the computers into the hallway—I moved a math department computer, like I was supposed to know which one belonged to the math department. People are very territorial.
>
> I don't have it as bad as others in the Workshop. But I was making waves and people don't care if they're good waves or bad waves—they're still waves and people don't like that. But I am learning. There's rules here, and those are the rules. (9/27/00 personal communication)

When he introduced modeling ideas, he went to great lengths to keep the administration informed. He tried to be as open and as explicit as possible about what he was doing. His efforts were especially diligent with regard to assessment, because not only was assessment important to Noah and his students, it was also important to the administration. Throughout the course, he kept the administration up to date on his activities and the students' progress.

> Folks,
> As the final component of their ecology unit assessment, my accelerated biology kids will be using computer simulations to run experiments. They will be collecting and analyzing data from ecological models similar to the ones they have been working with in class. Then they will be asked to evaluate a model that is new to them. The sheet that will guide them through the experiments is attached. They will be doing this work in MS 106 and in the library's techno classroom at from 1:10 - 2:30 this afternoon. Feel free to observe. They did quite well on the short answer assessment I gave them on Friday, showing that they learned the curriculum and more! Thanks for your interest and support, (10/23/00 email communication to his administration)

Noah was very attentive to the concerns of his administration and, initially, they seemed to be supportive of his efforts:

> The academic dean liked Paper Catchers. He like the combination of hands-on and intellectual stuff. I ran into the headmaster in the hallway. He liked that I was using technology to support learning and not just for technology's sake. (9/27/00 personal communication)

During the semester, modeling became a central component of Noah's course. As modeling really took a hold in his class, he shared his successes with his superiors:

> Friends,
> Though the definition is simple, the concept of evolution is a very difficult one for students to internalize. Working with them and their models has brought this fact home to me. They can see and know that the distribution of colors in the model has changed, but when asked if the population evolved, they could not answer. The connection between the word and the action was difficult for all of them. Same was true for (natural) selection. So we have slowed down.

> I think what's more interesting, however, is the feeling in the room during class time. Whereas in the past, confusion was accompanied by anxiety, students seemed comfortable being with confused. When they say, "I don't get it." I say, "That's OK, you will." And they believe it. A change in me has accompanied the change in them. Whereas in the past, their confusion was accompanied by anxiety in me, I am now comfortable with them their state of confusion. I can see the concept forming below their sense of awareness and I can nurture it. It's really cool. (10/27/00 email communication to his administration)

Even though he kept the administration informed of everything he did, and they never expressed any dissatisfaction, at the end of the semester everything broke down. Some students in the other biology section (taught by a different teacher) complained that while Noah's students got to do non-standard activities, they were required to perform more traditional tasks like writing "book reports."

> Recently [my use of StarLogo and other modeling materials] has been a source of conflict [with my administration]. I have had to prove, via standardized tests, that my students were getting the content they were supposed to. The fact that they got good test scores was not taken as validation of modeling.... it merely meant that the modeling would be tolerated.
>
> For next year, I asked to teach both sections of the accelerated bio course...so that work with models won't have to be compromised by comparison. I plan to spread the model use more evenly through the year...and hope to add models for speciation, positive and negative feedback loops.
>
> It is always difficult incorporating new material into your curriculum. The biggest roadblock was a perception that my students were playing. My chair suggested that I use the material with my [lower level] conceptual class, when in truth [StarLogo models] brought my kids to an intellectual level rarely reached in high school. (3/1/01 email communication)

In spite of this setback, Noah is still optimistic.

> I'm looking forward to doing some modeling again. It's a good creative/productive, non-political outlet. (3/2/01 email communication)

Path 2: Julie

Julie teaches 7th grade science at a public junior high school in a small, affluent, suburban town. She has been teaching for almost two decades and, perhaps because of her experience, is afforded a high-degree of trust and flexibility by her administration. She came to the Workshop, after a colleague told her about it, because she was interested in "developing technology projects that closely parallel [her] curriculum."[23] She had very little previous experience using educational technology.

During the Workshop, the technological aspects of model building came close to overwhelming Julie. But, by drawing on her extensive teaching experience and comfort with a particular activity from her class, she created a pathway to understanding model building and created a model that she could easily integrate in her courses. Her perseverance enabled her to reach two important goals—she became more technologically fluent, and she created a new resource for her science classes.

---

[23] Pre Workshop survey.

Highlights of Julie's story:

- Initially, she struggled with modeling, but she used her existing knowledge and skills as scaffolds while she developed an understanding of modeling.
- She tightly integrated modeling activities with her existing classroom practices.
- She faced typical difficulties at school.
- She is interested in implementing technology in small ways but is not looking for wholesale transformation.

Developing Fluency with Modeling Tools

Julie spent the better part of the second week of the Workshop working on a model called "Oh Deer!" based on a game that she plays with her students. During the final pinup, Julie described the game. In the game, some students are deer and some are pieces of the environment. Every round, the deer-students decide what resource they need (food, water, or shelter) and the environment-students decide what resource they will provide (food, water, or shelter). Then, on Julie's command, the deer run out in search of resources. If a deer finds the resource it is seeking, it turns the environment into a deer for the next round. If a deer doesn't find the needed resource, it dies and becomes a part of the environment in the next round. Eventually, she introduces wolves to keep the deer population in check. Here, she describes how she will integrate the StarLogo Oh Deer! model that she built with her existing lesson:

> Julie: I'm a junior high science teacher. And one of the games that I like to play with my students is called Oh Deer! When I play this game with my students, I play out on a football field or out on the track… In a class of about twenty kids, [I play the game to] illustrate population oscillations. I spend a lot of time talking about predator-prey relationships. And this is a really good way of showing how a predator introduced into a population can be used to keep a population under control.
>
> So what I do right now is I play the game for ten or fifteen [rounds]. Or I play the game for about ten [rounds]. And then what we see is the population goes way up, then it drops way down. Way up and way down. And when I tell them is, this is not what we want. We don't want a crash and burn situation. We want to get a nice fluctuation in the population.
>
> So right now we play the game [on the football field]. Then, we come back in [to the classroom]. We graph it on graph paper and we talk about limiting factors and so forth. One thing I came into this [Workshop] with was the idea that if I could walk away with a computer model of it, then not only could we go back into the classroom and do the simulation, but then we could really play with the variables. Instead of playing day after day to get five graphs, we could do five graphs by just making the variables change on the computer. So I'll show you how this works.
>
> I'm using a much larger population [in the computer model], obviously. What I'm going to show [the model] with is a total environmental count right now of five hundred; fifty of which will be deer, four hundred and fifty will be the resources around here. I'm choosing much larger numbers because as they start to move randomly, it takes way too long to wait for the deer to get to the end of the first year.
>
> What I really see my students doing is being able to play the game [and] get a really good feel for what's going on. Then coming back into the classroom and asking themselves, and my asking them a lot of questions about what would be a real stable combination of numbers in this environment? What happens if we bump the wolf count up too high? And I said, I suppose we could always throw a hunter in or something, or some wolf traps or something, is another thing if the wolf population gets out of control. (Final pinup)

Figure 21: Julie's students playing Oh Deer! on the football field.

Julie's final presentation highlights her strategy for success in the Workshop. She made the Workshop relevant to her own perceived needs by connecting her model directly to parts of her existing curriculum.

In the past, Julie had made numerous efforts to attend other technology conferences and workshops, though nothing had ever really worked for her back in her classroom. At some of those workshops, participants were asked to rate their computational capabilities. She rated herself a 0 or 1 on a scale of 0 to 4 (with 4 being most capable and 0 being very uncomfortable with technology). At the end of the first week of the StarLogo Workshop, she expressed a high degree of frustration with her perceived inability to build models as quickly as other participants. In her opinion, we should not have opened the StarLogo Workshop to participants with a variety of levels of technical skill. She felt that she would have been more successful in a workshop where none of the participants had any technical experience.[24]

To increase her comfort with computer modeling activities, she based all of her early modeling projects on things of which she already had a good understanding. She began to feel more affinity for StarLogo models very slowly, and the path that she took toward fluency never strayed far from her own classroom activities. Here, she describes a model that she and Will built to illustrate how light passes through a filter. Their model is an illustration of a simple process, rather than a true simulation (see Chapter 4). Her lack of fluency with the tool underlies her comments:

> Julie: As we started the project, we started to realize that we were running a little short on creative ideas, at this point, after having done a couple of projects, so we went a little bit on the practical side. What we did was create a light filter: a red filter, a green filter, and a blue filter. And then, take random colors and pass them through the filters, and select what will pass through, based on what has the pigment in it, what has the color in it. Only colors that have the green in it pass through the green filter and will be changed to green. Any colors within the red range will change to red, as it passes through. Any white color, white that goes through will change to the color of whatever respective filter it goes through. We thought maybe we could use it in school. (Challenge 4 pinup)

[24] 7/20/00 personal communication.

Julie exhibited a substantial degree of uneasiness with technology but a very high degree of comfort and self-assurance with her own abilities as a teacher. She drew upon her existing capabilities to help increase her confidence with modeling technologies.

During the Workshop discussion in the first week, she explained the value she saw in our Adventures Activities. She related our complementary use of Activities and computational models to her own pedagogical strategy of using games to directly involve her students in exploring scientific concepts.

> Julie: I find [the Activities] actually quite practical because a lot of times that's actually how I see using some of the stuff we've done...
>
> OK, in studying populations I explain a little bit about populations, oscillations and so forth. You go outside and play with your deer. Then if I had a program that we could come back in—you know, whether it's been developed or whether it's canned or whatever—I could come in and we go back to this computer lab and you know we've done the graph outside and we've done the rough version of it, and then we come down here and we start playing with the numbers on the sliders and seeing what would happen if we did this. Then I feel that the kids really need this really good handle. They've seen what population graph looks like in the book. They have gone out on the football field and they think [I am] crazy again because we're running all over the place. Then we come back in the computer lab and bingo, you know, the things that we predicted out on the football field is what's happening on the graph.
>
> And that's where I see the translation between what you've been doing, you know, I've seen some things that we've done [in the Workshop] that maybe I can make a little game out of it. That would work with some of the other things I do and then put the computer piece with it. (Workshop discussion)

The inclusion of the Adventures Activities in the Workshop provided a pathway for her to envision integrating modeling technologies in her classes. She distributed copies of the Oh Deer! activity in the first week of the Workshop and it gave her a foothold, even as her programming experiences were coming along very slowly.

> I love to use a variety of techniques to teach a concept. I find that every time I use something different, a couple more kids get the point and those who already had it move to a much deeper understanding. Star Logo (and other models as well) gets the kids' attention and make it seem like fun instead of work. (Isn't that what it's all about?) The more visual or physical the better. (2/5/01 email communication)

During the first week of the Workshop, she and Bea discussed the Oh Deer! activity over lunch. Bea was interested in learning more about it, and Julie, who was an Oh Deer! expert, subsequently offered to provide everyone in the group with a copy of her activity. Her conversations with Bea and her consistent desire to build a "project that [she could] use right away"[25] spurred her to try to model Oh Deer! in StarLogo. Julie chose to use modeling to complement a well-established, and highly effective, activity in her science classes. In the pinup for Challenge 6, she explained her rationale for designing the model and her initial attempts to include functionality that mirrors her classroom activity:

> Julie: Bea had asked me for a copy of the worksheet on Oh Deer! It was a game I explained to her where deer go out and look in the habitat for what they need. What we're trying to do is build a computer simulation of it. I thought it would be very practical for me, in the classroom, to go out and play it outside,

[25] Pre Workshop survey.

> and then be able to come in and instead of drawing it on graph paper with the kids, have them be able to run the simulation of it. (Challenge 6 pinup)

It is evident in her description of the StarLogo version of Oh Deer! that she was trying to faithfully recreate this activity on the computer. In the first version, the StarLogo model has only 24 turtles, to correspond exactly to the number of students she has in a typical class.

> So what we're doing so far is we have it to the point where the deer count is four, because generally, in a class of 20, I have four kids who started as four deer. Then, you can set the resource number. The resource number represents either shelter, food or water, which the kids who are part of the environment can choose each time what they want to be. Actually, you know what, let's bump the resource number up to 20; that's going to simulate a class of 24—20 kids being in the environment and 4 kids being deer.
>
> When we hit 'Run', the deer are going to head out and look for a mate in the environment. It can supply them with—well, not a mate, but a piece of the environment that would satisfy what they need. The green look for green, blue look for blue, yellow look for yellow. Yellow is shelter. When they find a match, they are going to turn magenta, because they are going to turn that piece of environment into another deer. Because once they've found what they needed, the deer is going to reproduce. The next piece for us would be when we learn how to graph too, to take this first piece and show it on a graph so the kids can see that the piece is working. (Challenge 6 pinup)

At this point, though her model is simulating a predator-prey system, in her mind she is really only reproducing the process that her students carry out on the football field. She is not yet ready to dive into exploring a simulation that deviates at all from the one she runs in class. Her deep understanding of and extensive experience with the Oh Deer! activity informs the design of her project and gives her a comfort zone whenever the computational modeling issues became challenging.

By the final pinup, Julie had several well-developed strategies for building modeling fluency. Not only did she rely on a domain that she knew well to move from building an illustrative model to creating a true simulation, but she also relied on other "real world" tools to substantiate her growing understanding of modeling. Here, she describes two strategies for creating her model, first borrowing code from another participant and then using a stopwatch to calibrate her model:

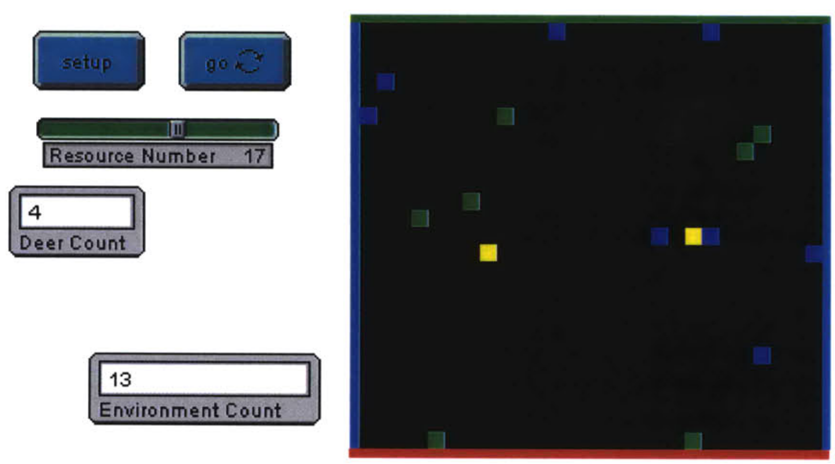


Figure 22: The Oh Deer! model. The deer are blue, yellow, and blue in the center-right portion of the environment. The resources are scattered across the screen.

> Julie: Lawrence
> strikes again. [laughter] He had his, I think it was your ships, that if they—in a period of time if they

> didn't reach Europe then, um. But in the code it is set as a time factor, where the round ends after a period of time, and then it resets for the next year. What George and I started out doing was actually timing—starting the deer movement and timing how long it took for most of them. When I play with my students, the first two rounds, everybody should find a partner, but then when we get up to 16 deer and you've only got maybe ten people left in the environment, that's when it starts to drop off. So we actually timed it physically on a watch to see about how long it was and how many moves that was—it required to do that. And then went back and used some of [Lawrence's] code as far as setting the parameters for that. We kind of tried to get a feel where we wanted [the deer] to be successful in the early rounds, but yet as the numbers went up we wanted it to show that there was a population drop. (Final pinup)

Though Julie initially stuck to replicating precisely the game that she played with her students, over time she used her model as a point of departure for exploring facets of predator-prey interactions that were not part of her classroom game.

Integrating Modeling in the Classroom

When she was ready to bring modeling activities into her classroom, Julie again relied on tying those activities to the traditional teaching methods that she already employed. Just as her knowledge of Oh Deer! helped her to develop a clear understanding of modeling during the Workshop, her pre-existing use of the game gave Julie a clear path toward integrating the StarLogo model in class. At the same time, she began to draw upon the strengths of the computational medium to allow students to conduct deeper investigations that they could through her traditional activity. During the reunion, she described her plans for integrating modeling in her classes:

> Julie: So now what I am looking forward to when we do the unit is going out to play the game and then coming back to computer lab. And not having just the one parameter—now we have one wolf—now we introduce five wolves at a time and see what it does, now we have this much larger population. And, it graphs across the bottom so as soon as they introduce something instead of waiting to count it will automatically go into the plot.
>
> I see it as a tool to look at the same thing from a different perspective. And to give the kids a different perspective on, you know, graphing isn't just pen and paper, graphing can be done a larger scale.
>
> Male: So you're taking something that you're already doing and kind of growing it?
>
> Julie: Yes. Right. That's how I chose to do it. That way I felt that it was definitely part of my curriculum and it was a fun part of my curriculum. The kids love going outside on a football field and playing. What could be more fun than going out and playing the game then instead of coming back in and actually drawing a graph go to the computer lab and now play this on a computer and see what happens what you talk about a much larger population. (Reunion)

In addition, to providing a hook to Julie's curriculum, her decision to combine StarLogo modeling with an activity in class eliminated any need for extensive explanations of StarLogo to her students. The students already had an experiential understanding of the simulation when they were introduced to the model, so StarLogo was simply a different medium for a familiar simulation. Thus, she didn't lose any class time even though she added another component to her lesson.

Overcoming Technical Difficulties

A large barrier to integrating new tools in the classroom is simply the lack of access to computers, even in very well funded schools. Like many other teachers, Julie encountered a number of technical difficulties as she integrated modeling in her classes. As the school year got under way, she updated us on her plans to run the Oh Deer! model with her students:

> Yes, I definitely am planning on doing Oh, Deer! but all I can tell you right now is that it would be in the late fall. There are some issues revolving around the use of the computer room right now (someone is teaching in there 5 periods a day so scheduling is tighter than ever). (9/13/00 email communication)

Once she secured access to the computers, she had to call on her part-time technology coordinator, who was inadequately prepared to perform even basic tasks for Julie.

> I have forwarded [a version of StarLogo Oh Deer!] to the computer people [at my school]. I'm not sure where they stand in getting this rolling. I am keeping my fingers crossed. This is not a good time to attempt new technology ventures. (11/27/00 email communication)

The next day, Julie's technology coordinator wrote to us because she was unable to open up the program. It turned out that she had failed to install the StarLogo application.

> I am trying to help Julie. Today I downloaded the StarLogo 1.1 for Macs. She would like me to open up a document called "deer.slogo" which you forwarded to her at home. At home she has a pc. The deer document worked on her home pc. Here we have only Macintosh. I cannot open up "deer.slogo" with any program we have access to. (11/28/00 email communication from the technology coordinator)

After Julie finally ran Oh Deer! she came up with more ideas for modifying her model and learned more about technology than she had probably bargained for:

> We increased the virtual memory and utilized every other computer. The combination was very successful. Since we had no glitches, the kids on Friday had about 40 minutes to play around with it and had a lot of fun. If I were to make improvements on it they would be: 1. Change it so that when you increased the Total Environment slider, the deer would proportionally increase with the habitat. Right now the deer always stay at 50 and just the habitat increases. 2. Find a way to kill off wolves when they get out of control- A hunter button? (One kid got up to over a thousand wolves and only 4 very nervous deer before the wolves crashed from lack of food.) It seems like a realistic solution.
>
> As you have seen, this is a difficult year with technology at my school but I'm still glad we got to try it out. "Come the revolution" when all the labs are up and running, I would love to do more with StarLogo. (12/2/00 email communication)

Reflections

Julie wants to be innovative, but is still quite cognizant of standards and requirements. That said, she is willing to bend the rules when she feels that her efforts will result in good learning situations for her students.

> I wish I could take a whole block of time but with the frameworks, it's just impossible. Are you familiar with the frameworks? They are about 10 miles wide and an inch and a half deep. No one can teach like that. I could teach what the frameworks require in geology in about 25 minutes, but I don't do that—I take a whole semester because the kids need to really understand that. (11/29/00 personal communication)

With her StarLogo model, she was able to modify and extend a piece of her curriculum that she felt was important for her students to fully understand. With the computer, her students could "look at the dynamics of larger populations"[26] and investigate the effects of large wolf populations—explorations that would be impossible without the computer. Reflecting on the experience, she said:

> I wouldn't say that [the model] "changed" the way I ran the Oh Deer! piece but more that it "enhanced" it. The kids have always enjoyed going out and playing the game but this was a big plus and it kind of really drove the point home in a fun way. [The model] really helped solidify the concept of population fluctuations, graphing and to a certain degree the concept of modeling. They really thought it was very cool that I had any part in creating something that could parallel the outdoor game. Though I didn't work with them specifically on modeling, they came up with some great ways that they would make modifications if they could. (2/5/00 email communication)

As she said, she did not focus specifically on modeling in her classroom integration of StarLogo, but by bringing in facets of her Workshop experience she introduced her students to a new way to think about populations. And, she may have started to think about her own talents and knowledge in a different way. She created a computer model that her students used in class and now other teachers in the school are also becoming interested in what she has done:

> My teammates were really interested and I must say impressed with the outcome. The kids told the math teacher quite a bit about it. Sandra stopped by the other day and asked if I could run through Oh Deer! with her so that she could do it with her classes. Another 7th grade science teacher is going to use it as well, so it is getting more use. (2/5/00 email communication)

Next year, she is contemplating adding other modeling exercises to her courses:

> I would certainly use [StarLogo] in at least the same capacity and I would like to use some of the other games like "flocking" etc. to simulate other concepts. I was also planning on looking more closely at the "Fish Pond" [a model that was developed at the Workshop by other teachers] to see if there might be a place that I could use it. I really see it as a valuable visual tool that my students would enjoy as well as learn from. (2/5/00 email communication)

Julie came to the Workshop with a mixture of curiosity and fear about technology. Our combination of Activities and computer modeling allowed her to make connections between our pedagogy and her own. Seeing the connection between computer modeling and Activities enabled her to integrate technology in her classes—something that she was not able to do successfully in the past. Now, modeling is becoming a pathway to collaborating with other teachers in her school.

Path 3: Carl

Carl is a middle and high school computer teacher at a private school in a small New Mexico town. He has been at his school for seven years. Before that, he was in industry, teaching adults programming, systems analysis, and database design. He has tutored mathematics at youth shelters for many years.

Carl attended our first StarLogo Workshop in the summer of 1998. Because of his interest in StarLogo, we invited him back as a mentor for the student Workshop in the summer of 1999. Carl, and another teacher from the 1998 Workshop, also ran a student Workshop in the summer of 2000. For the past two years, Carl has held an evening computer modeling class for students

[26] 11/29/00 personal communication.

from his school and other schools in the area. Beginning in the fall of 2000 interest in StarLogo at both his own school and in the surrounding community has taken off.

Now, he is moving far beyond his school, running StarLogo Adventures Workshops on Native American reservations and at a local Boys and Girls Club that houses a computer clubhouse. These more geographically diverse projects are still in their infancy, so here we look specifically at how Carl influenced his own practices at school and how those changes are starting to influence other teachers.

In Carl's case, we will explore how he:

- Used his understanding of modeling to strengthen his role within the school, and minimize his need to perform systems administration duties,
- Reached a point of believing deeply in the scientific utility of modeling,
- Relied on his new found understanding to reach out to teachers, and
- Used modeling as a platform for significantly expanding his role outside the school.

Defining His Role in School

Through his work with modeling, Carl has filled out his notion of what it means to occupy the position of technology coordinator. It has given him a means to help teachers tie their content to technology and it has helped him to reconsider the role of content in his own computer science classes. It has provided him with wings to expand his own influence both within his school and beyond.

As part of his job as technology coordinator, Carl also performs system administration work at his school. This part of his job could easily monopolize his entire workday, and he finds it tedious and unfulfilling. Working with teachers and students using StarLogo has allowed him to find satisfaction in his position, by enabling him to construct a niche where he can deliver added educational value for students and teachers. At the same time, he has leveraged the demand for his technical skills to increase the amount of time he can allocate to pursue his modeling interests. Last fall, he almost quit his job until the headmaster agreed to hire a part-time systems administrator to relieve Carl from some of those duties. The fact that he is willing to perform systems administration duties for low pay (a difficult position to fill) makes him a valuable asset at the school, and he trades his technical skills for time and support from the administration:

> I didn't take a pay cut to do what I did on the outside [systems administration]... My principal asks, 'so, is this modeling stuff keeping you happy?' (1/24/01 personal communication)

At the October Reunion dinner in Boston, Carl described his role.

> I teach computer classes at my school and I am the technology director for the school as well. I get to do a little bit of teaching and also supporting the teachers with what they are doing. I am hoping to use that position to see how I can support the teachers by injecting some of these modeling ideas into what they are doing in a way that makes them feel like they are not losing time from other things.
>
> I have been involved in the program for three summers at Santa Fe Institute and I started introducing it during the school year last year in my school. In my 9th grade applications class I was able to—because projects were a substantial component of the course—give the students an option of doing some kind of a model. Most of the kids took to it, some of them in a big way, and some of those kids ended up in our

> Workshop for high school students. This year I have started working with a middle school program, with a newly designed class that's mostly seventh graders, which is an elective with a mix of different kinds of exposures to technologies. And the thread that sort of ties it all together is working with StarLogo and modeling. (Reunion)

Modeling as a Scientifically Valid Approach

Initially, Carl tried to bring modeling into his school by working with students in his own computer classes.

> I am trying to corrupt the school I'm at with these kinds of ideas. Since it [requires teachers to] give up too much time in science, I've created a computer department at school to introduce these concepts. [I'm] increasing the general level of knowledge about StarLogo in school. Then I can push into content domain with support and a base of kids who are familiar with the program. 40-50 out of 300 is a significant level of student experience without raising the hackles of the science teachers. I am decreasing their investment and increasing the kids' ability to use. (Reunion)

Though he felt modeling was "worthwhile" he did not have a well-formed belief about using modeling as a tool to think with.[27] Instead, he focused primarily on StarLogo as a tool that kids could create with:

> I also like StarLogo as a gentle and forgiving introduction to programming and building software tools. One can build a working application, if not a model, in a very short time with relatively little training. (3/29/01 email communication)

Carl pursued the use of StarLogo primarily as an interesting programming tool for most of the first two years that he worked with it. This was quite apparent to several researchers at the Santa Fe Institute (SFI), who commented at the end of the 1999 student Workshop that the students had not explored or investigated the models they had created.

Last summer, two experiences led Carl to embrace experimentation and exploration as key components of the modeling process. First, before his student Workshop in the summer of 2000, Carl met with two researchers from the SFI,[28] where an ongoing debate about the scientific validity of models was raging, to discuss ways to involve the students in exploring and investigating models. Later that same summer, we invited him to a meeting to discuss scaling the Adventures in Modeling Project. Two of the big topics of conversation at this meeting were how to make modeling relevant to the curriculum and what kind of educational research is necessary to validate modeling as an approach to building knowledge. After the meeting, he commented on the importance of moving "towards increasing the inclusion of experimentation"[29] with modeling.

As a result of these events, Carl became convinced that modeling is a valuable tool to think about particular issues or problems. This change significantly increased his level of excitement about

[27] We suspect that this is partially due to the fact that he was a participant in the first StarLogo Workshop, in which we did not focus as much on thinking with and about models. Instead, we focused almost exclusively on teaching the teachers to build models.
[28] Thanks to Erik van Nimwegen and Timothy Hely, resident scientists at the Santa Fe Institute, for their valuable input.
[29] 10/11/00 personal communication.

modeling and altered how he thought about using StarLogo. He began to think about how modeling could have stronger ties to the curriculum.

> At the end of the summer it really hit me that math is horribly taught and [modeling] could be used really well there. Kids have trouble with percentages and fractions. (10/10/00 personal communication)

It took a while for all of these ideas to solidify. In December, he was still not having success reaching the teachers.

> I've had so little luck reaching the teachers—maybe we'll just have to start with the kids… I'm putting a lot of thought into how to connect with the teachers. The more we have models that connect with what they're doing, the happier they'll be. (12/5/00 personal communication)

As his views about how to use modeling changed, his vision of how to bring modeling into his school changed as well. Now, he did not have to be covert, bringing modeling only to the students, but he could approach the teachers directly. In the fall, he co-authored a paper discussing the transformation from building models just for the sake of building to building and exploring models to understand patterns and processes (Taylor, Noll, Klopfer, & Colella, 2001).

Pathways to Reaching the Teachers

After Carl reconceived his notion of modeling, he began to emphasize the connection between modeling and scientific investigation. This new approach was much more palatable to teachers, as they saw a more direct connection to their curricula than they had when Carl's emphasis was solely on model building. One of his first efforts came in the fall when Carl pitched one of the Participatory Simulations to the middle school science teachers.

> Our middle school science teachers were so interested [in the virus game] that they wanted to design a module around this where it would lead beyond just simply running some Activities and having some discussion about it. But actually leading somewhere else with it—making it part of what they're doing and learning how to think about science and learning how to discover what goes on. Even perhaps then we could generate data, maybe bring in spreadsheets and have the kids analyze it, do write ups and so on. (Reunion)

His excitement about both their interest and his growing belief that modeling can be connected to scientific exploration are evident.

In the fall, he conducted Participatory Simulations for both the 7th and 8th grade science students:

> We did the badges in the middle school—the upper school is still more resistant, even to the process, not just to the time [it takes]." Virus badges have contributed to very high level of excitement and enthusiasm at the school, even among the science teachers. 8th grade teacher's reaction, "anything I can do for you just name it. This makes me look wonderful to the administration." "There is a tremendous enthusiasm for the kind of energy that the kids exhibited." "And the teachers really liked that approach." "The 7th grade teacher is almost a technophobe and is even more enthusiastic. [He asked] is there some way we could make this part of the curriculum, bringing in models as well." (10/10/00 personal communication)

> Joe (an 8th grade earth science teacher at Carl's school): I guess it started with the virus badges in the fall. When we both saw the kind of scientific thinking and redesigning and re-experimenting and re-editing which we don't have time to do—or don't take time to do—in our labs. We could, but we don't. [With the badges] the kids could change their variables in any way they wanted to, and that was an incredibly

powerful experience for them. And for us, for me as a teacher and for our kids. And, I think the big thing about that was probably for them to see the value of failure. They previously thought failure was, 'Oh, the experiment didn't work.' That it was bad. With the computer you can immediately say, 'Oh, it didn't work. Why? Well, let's tweak something.' And, our kids were on fire in both of our classes after that, after the virus badges. (1/25/01 personal communication)

Eventually, he constructed a story that integrates his earlier attempts to subversively bring modeling to the students with his current effort to reach teachers.

I see some interesting possibilities between that... you know the couple of dozen kids that I have in middle school computing. They'll be scattered more or less evenly throughout your sections and it'll be interesting to see what kind of effect [they have]. If they have the freedom to say, 'You know, I'd like to fiddle with this. I think I'll save it and then after class or tonight I am going to tweak this and see what happens.' And, all the kids don't have to be doing exactly the same thing. Some of them could say, 'Hey, I've done this with it.' And the other kids will see how models can be pushed a little bit further, if they are really interested. (1/25/01 personal communication)

He became convinced that modeling can change how people think about and understand mathematics and science.

The middle school teachers are into it. They liked the virus badges. There is a lot of enthusiasm. What they might do with the curriculum is hard to say, but they are into systems thinking. No big changes yet, but they aren't doing much yet. We are discussing where they might go. They are very open to suggestions. I am thinking about how I could help the middle school teachers to change the way they see science & maybe include teachers at other levels in math and biology. (12/5/00 email communication)

He enjoys being a mentor to the teachers and his knowledge of StarLogo and modeling have given him a platform, which he did not previously enjoy, for teaching them and collaborating with them.

I am helping my teachers to integrate StarLogo in mathematics, pre-calculus, and biology. I can work with [them], develop what [they] are doing with the model, and support [them] during class. I have a really good relationship with my teachers. I give them a lot of support. (1/24/01 personal communication)

The following conversation illustrates how Carl became willing to adapt to the teachers' needs and learned to help them strategize new ways to integrate modeling into their classes.

Carl: When we do this in the future, you will have—you can always invite me in to be that additional support. It's not quite as much, but certainly you don't have to pay attention to the technical issues as well as to your lesson. And, I love playing that role so it is perfect.

Joe: I think, going back to the earth science issues. That makes it more difficult [to model] perhaps because there aren't as many discrete units to follow and track. And then as we talked about that this morning and we started to build that little carbon dioxide model. It really intrigued me to just say, 'Hey, I'm going to go build it.' I am looking at Carl—we're going to go build it, you know, and see what we can come up with. Because, the model, the being able to change the variables in a multi-dimensional experiment is fabulous. You know, it's the way it [science] works. I don't know how many variables we can tweak and get how many different things happening at once in StarLogo, but let's find out. I may need some technical—you know I can't—I am probably not ever going to be versed well enough in StarLogo—

Carl: But I can always help you. And even if you do do some building yourself you can run it by me or we can sit and work on them together.

Joe: Right.

Carl: Whatever.

Joe: Could I give you a model of what I wanted and then either you and I work on it or—

Carl: We can discuss it occasionally.

Joe: Yeah, say, here are the parameters, I don't have time to do it. I am busy doing my class. Is there somebody that could do it? Is there a class of kids that you have or is there?

Carl: That's possible. It's possible that I could do it. It's possible that I could talk to these guys and we could have someone work on it, and between all these possibilities, sure. Given enough warning, for sure. And if it's a simple model, I can probably whip it up in an hour or two.

Figure 23: Students from Joe's earth science class run experiments with a model of crystal growth in Carl's computer lab.

Joe: And, I think the follow-up conversation to have is—educationally—when we took the summer project [Workshop] at the Santa Fe Institute, the emphasis was on learning to program StarLogo, and for the students to come in—for them to learn to program StarLogo based on their own models. And at that time, I said to myself, that's not going to happen for every man. You know, that's not going to be an every man kind of thing, but the star kids are going to be able to do that. As I am doing this here today, it's reinforcing (and with the virus badges) the power is in the things like Ron was talking about. Being able to see how systems work when you change various variables. And I think that's really the lesson, at least in middle school—not learning to the StarLogo language. So the question is, we still need facility with it at some level in order to do what we want to do. And ideally for the kids to be able to go into StarLogo and tweak it programmatically. That would be an ideal. And, I don't—you know, how much class time would you give out of your earth science class or your life science class teaching them to write the program? Versus just tweaking the program.

Ron (a 7^{th} grade life science teacher at Carl's school): That's where, as soon as we become a more integrated middle school, the computer classes and the science classes can be running units concurrently that are reinforcing each other.

Joe: Perfect. (1/25/01 personal communication)

Through Carl's efforts, modeling became a platform for improving practice in particular classes and a substrate for expanding faculty collaborations.

Looking Outward

At the same time that he began to reach the teachers inside his school, Carl became increasingly interested in bringing modeling to other communities, especially underserved communities in his state.

All sorts of lively stuff going on in northern NM: the Boys and Girls Club, a middle school and one of the high schools… we've been asked to come to Cimmaron up near the Colorado border (a much shorter drive

> than Shiprock, I am working remotely with two teachers from TseBitAi on a two-school collaboration, and activity in Shiprock is working towards both an April one-day and some summer activity. Whew! (3/27/01 email communication)

Carl has had a personal interest in programming StarLogo models for the past three years. His ability to reconceptualize the role that modeling can play in building new understandings has enabled him to bring his enthusiasm for modeling to others.

> I also had a meeting with the Star Schools folks from UNM, Oklahoma State, and the US Dept. of Education. Along with a couple of local economists (one with UNM and the other a private company) who do modeling in Stella and wanted to learn about StarLogo... Many of them were very interested in what I had to say, and had many questions. The primary reason for my being at the meeting was to discuss the modeling phase of the evaluation of the distance learning project at OSU. I took the opportunity to pitch StarLogo as a tool for permitting process exploration in the project's web lessons, to a positive response.
>
> I was also taken aside afterwards by the Dept. of Education person, [a director] with the Office of Educational Research and Improvement. He asked me something about serving on a panel in Washington. Weird, huh? (3/31/01 email communication)

Carl is proud of what he is accomplishing and continues to put a tremendous amount of energy into building a community of modelers from diverse socio-economic conditions. In spite of his growing expertise, like many teachers, he is not accustomed to being considered an expert by someone outside of his local community.

Path 4: Cathy

Cathy is a motivated, well-prepared new teacher. She is in her second year at her current school, a public elementary school in Chicago, and her fourth year of teaching. 85% of the students in her current school receive free or reduced lunch. Previously, she worked for some educational programs outside of the school system and did work in classrooms through those programs. Cathy is an energetic, motivated, and reflective teacher.

As the technology coordinator and librarian[30] in her school, Cathy is responsible for teaching media to all of the school's 360 students and selecting technological and other resources for the school. Cathy doesn't like most educational technology and is aware that research shows that "computers in poor schools tend to be used more for rote drill and practice and less for actively involving higher-order thinking skills."[31] She sees herself as a researcher and is always on the lookout for "opportunities to avoid the 'workbook-on-wheels' approach that is used with so many classroom computers."[32] She is eager to explore on her own and willing to involve her students in her explorations.

Cathy is confident with technology, though by no means a computer expert. She is good at improvising and has a clear sense of the kind of active learning in which she wants to engage her students. She has a supportive administration that places few constraints on her activities. Yet, the student population in her school presents the typical (but non-trivial) challenges of an inner-

---

[30] Though she does not hold a library certification, she gets paid by the library line and so must perform some library related duties for the school. (10/5/00 personal communication)

[31] Workshop application.

[32] Workshop application.

city student population. Among other things, many of her students speak and read very little English and almost none has any technical skills.

In Cathy's case we will investigate:

- The steps she took to deciding what aspects of modeling to implement in her courses,
- Her strategies for reaching out to teachers in her school, and
- Her growing interest in working with a community of educators outside of her school.

Considering What to Change

Cathy was an enthusiastic, committed Workshop participant. When she returned to school, she was quite confident about *why* she wanted to integrate modeling into her classes but unsure of exactly *what* she wanted to do with modeling or *how* she would go about doing it. Cathy described her motivation for including StarLogo in her classes:

> I often have the opportunity to see how different schools use technology in their curriculum or to see what kinds of software products are available for schools. People talk about technology's ability to foster higher-order thinking, creativity, inquiry and problem solving, but in reality, it's difficult to find models where this potential is realized. It's so frustrating to see powerful machines used merely as flashy workbooks or elaborate typewriters, and it's downright frightening that so many people view these uses as "technology integration".
>
> I'm excited about StarLogo for many reasons, but mainly because it passes two critical standards for meaningful technology use: fostering inquiry and thought, and adding something to the learning environment that isn't possible with traditional tools. StarLogo provides students with a manipulable, interactive environment in which they can experiment, test hypotheses, and observe phenomena in a manner that isn't possible in the physical world. Students can explore the interrelatedness of different variables in, for example, a simple ecosystem. They can add and remove factors from the model ecosystem to observe how they contribute to the whole. They can pose questions and explore them and truly use the computer as a thinking tool.
>
> Most so-called educational software puts the student in a passive role. One of StarLogo's greatest strengths is that it engages the students with the technology in ways that most software does not. For most students, StarLogo provides their first experience having technology be so responsive to them. They can manipulate the StarLogo environment to explore questions of interest to them.
>
> When I began learning StarLogo, I thought to myself, "Finally! Here's something that does what educational technology claims to do." In my opinion, it's one of the few truly valuable computer tools available for use by students. It makes a genuine contribution to the learning process, rather than just dressing up (and dumbing down) activities that are better done with pencils or blocks. (1/9/01 email communication)

Recognizing the aspects of modeling that were appealing to her philosophy was something that Cathy could do on her own, but when it came time to make pragmatic decisions about when and how to integrate new activities in her classes, she felt hindered by the absence of colleagues to consult. The lack of a community of practice around her made it difficult for her to make tangible progress. She frequently emailed us when we prodded teachers about their progress in the fall.

> I'm in the process of figuring out how I personally will be using StarLogo as well as how I might teach other teachers in my school about it. It's too difficult to approach teachers with new stuff in the first couple of weeks of school, but I'm planning on running an optional StarLogo info-session one afternoon in early September. I've mentioned the program to a few people who seemed pretty excited to learn more. In my

own classes, I'm thinking of using simulations I've created with the sixth graders this year and teaching the seventh graders how to create some of their own simulations. This could lay a foundation for some more in-depth work in eighth grade next year. Our 7th/8th grade science teacher is fantastic, so I'm hoping to co-plan some of this with her.

p.s. I also have a regional technology coordinator who serves about 30 schools, and she's interested in learning more about StarLogo too—we might just get our own little colony started out here in [Chicago]! (8/24/00 email communication)

Though she recognized the importance of a community of practice, both for her own development and the success of bringing in innovations, she was not sure how to take the first steps towards creating one in her own school.

The 8th grade English/science teacher is thinking about social interactions. Maybe I should run a class for other teachers at school. It is hard to work without collaborators. (10/13/00 email communication)

Extending Her Community

About the same time that she was struggling with what changes to make in her classes, Cathy was encouraged by a colleague to make a presentation on modeling at an upcoming conference:

Last Friday at a meeting, my regional technology coordinator requested that I present 'what I learned this summer' at a conference on October 27th. The conference is run by the Board of Education for all technology coordinators from public elementary and high schools in Chicago.

I'm writing to 1) share that interesting and exciting (and a little scary!) news with you, and 2) to invite you to come co-present with me. Is this something you would be interested in doing? Please let me know ASAP. In either case, I will no doubt be sending you miscellaneous cries for help as I organize my presentation—consider this an early warning! (9/17/00 email communication)

Though we declined her invitation to co-present, she went ahead with the presentation. After the regional conference, she filled us in on her assessment of the presentation:

The presentation went well, I thought. I started out with a little spiel and then moved on to projects. I showed rabbits and grass, fishpond, and the forest fire one. I also showed the one where the rope makes waves of different frequencies, etc. People seemed very interested. At the end, I talked a bit about the book. Oh yeah, I also showed the website so they could have a sense of the resources available.

The main drawback was under attendance. I was pretty mad because they let the keynote speaker give another presentation—unscheduled, but announced over the p.a.—during my scheduled time. Needless to say, a bunch of people who might have come to my session went to keynote guy instead. Oh well, it was less intimidating with a small audience, and I think those who came learned something new. (11/17/00 email communication)

Despite the poor attendance at her session, Cathy's confidence and motivation to create an external community grew. She even decided "in a fit of insanity"[33] to apply to run a two-day workshop at the National Educational Computing Conference. Preparing for and giving seminars out of school helped her to focus on what kinds of modeling activities she wanted to pursue in her classes.

[33] 10/12/00 email communication.

Forging Ahead in School

As the first quarter drew to a close Cathy shared her plans for integrating modeling activities into her 7th and 8th grade classes.

> During the second quarter, I see the upper grade classes twice a week. I think I am going to start out the seventh graders on a slow, step-by-step version of the summer Workshop, hopefully building up to them creating their own simulations. This will hopefully lay a foundation for some more in-depth work when they're in 8th grade, including using simulations for some science fair projects, when appropriate. I'm not sure yet what I'll do with this year's eighth graders, but we'll probably explore and tinker with some existing models. (10/11/00 email communication)

In her 7th grade classes, Cathy integrated the Challenges and adopted the Workshop structure for facilitating student collaboration. She found that she needed to invent new strategies to meet the needs of her students. For example, the students had trouble thinking "inside of a turtle" so she had them get up and walk around the room, pretending to be turtles (Papert, 1980).

> I started teaching StarLogo to the seventh graders. We did challenge 1, and they loved it. Although most of them had trouble figuring out what the buttons did, they were able to experiment and generate designs they liked, and some of them discovered the paint tools. Also: seventh graders are not too enthused about sharing in front of the group, but I think they'll get over it. Tomorrow I'm going to have them work on creating their own buttons and swapping computers with other pairs to explore what their classmates created. Should be exciting! (11/6/00 email communication)

After her initial efforts with the students, her classes began to take off. Cathy integrated many of the Workshop materials into her own classes, and the students' successes fed her enthusiasm for continuing her modeling work.

> I am definitely going to do the graph paper [Pixelated Paths] stuff next week. It is hard for the 7th graders to abstract the square sequentially. (11/7/00 personal communication)

> Last week the seventh graders started experimenting with creating their own buttons. Next step: they're going to create buttons that instruct turtles to draw particular shapes. Should be fun! (11/14/00 email communication)

By the end of November, she was ready to share her successes with the Workshop teachers:

> Teaching StarLogo is fun! The seventh graders are working on creating their first buttons. They had some sort of free-form exploration time with painted turtles and playing with creating buttons, and now I've assigned them something a little more concrete (buttons that draw particular shapes, create turtles, clear all). We also did an off computer thing giving verbal commands to human 'turtles' to see how they follow instructions like `fd`, `rt`, etc. So far the biggest confusion is the difference between a turtle and observer command; also, the syntax baffles a lot of them. They know what they MEAN to say, and it's hard for them to understand that the computer can't figure it out unless it's exact. Overall, the kids are definitely challenged and seem to be enjoying themselves (although you know how 7th graders are—too cool to enjoy ANYTHING!). I think we're going to do the graph paper path activity [Pixelated Paths] after Thanksgiving. Happy holidays! (11/21/00 email communication)

> Do I want kids to build their own scientific models or just know enough StarLogo so they can better understand models I hand out? (10/11/00 personal communication)

Because her students don't have computers at home and technology is generally very intimidating to them, she felt that it was important to start with a blank slate, rather than with the sample projects. She wanted her students to build things up from scratch so that they could see how the program worked.[34] In her mind, the best approach to developing technological fluency was the *construction* of new models. "StarLogo is a lifesaver because all of the other computer programs, especially at the middle school level, are fixed. With StarLogo the kids see that they can actually construct something."[35]

This approach was difficult at times because the 7th graders had a hard time mastering the commands and syntax. In our experience, the combination of *constructing* new models and *deconstructing* existing models is more fruitful path to building fluency with modeling tools.

Cathy was able to take the Workshop materials and use them in her middle school classes to address issues that she perceived to be important, such as enabling her students to build something of interest to them on the computer.

> Using StarLogo changed the way I run my classes. With StarLogo, I felt I could give the students some basic guidance and then let them truly use their imaginations and trial and error to see what they could create and discover. I was able to be much more open-ended with StarLogo assignments than, say, with Internet research projects. StarLogo as a tool allows for a great deal of student exploration. A lot of people argue that one benefit of technology is that it enables you to teach in more open-ended, student-driven ways, and I think StarLogo has made that statement true—more so than many other tools. Whether the kids were experimenting with creating their own buttons and sliders or exploring populations with the Rabbits and Grass model, they were able to take the project and run with it. In every case, they discovered something completely new to me!
>
> I was motivated to use StarLogo because it is a high quality technology-based learning tool. As the technology specialist at my school, I am always looking for ways to use technology that will enrich and enhance the educational program in ways that traditional tools cannot. StarLogo fits the bill. It is highly accessible for students, and it represents real-world phenomena in complex, interactive ways. It's an exciting way for the students to interact with the technology—experimentation and exploration, rather than pointing and clicking. It puts students in a different, more active role in relation to the computer. Even doing something as simple as creating a button to make turtles move 5 steps gives the students a sense of empowerment—it shows them that they can make the computer do something, and that they can write commands that the computer can understand and execute. (2/26/01 email communication)

Fostering a sense of empowerment and engagement in her students is central to Cathy's educational philosophy. After the Workshop, she had an instinct that modeling could allow her to accomplish her goals. By taking on the personal challenge of presenting her work to colleagues outside of her school, she was able to craft, and subsequently follow, a clear path to infusing modeling into her curriculum in a manner that would empower and engage her students.

Reflections

Cathy's role in school is both as a teacher for the students and as an advisor for the teachers. She frequently invites other faculty to observe her classes when she is integrating new activities. In her experience, other teachers "need to see it and see how it works in order to want to do it."[36]

> I haven't used the [Participatory Simulations] badges yet but am meeting with the sixth grade teacher next week to see whether we can plan a mini-ecosystem adventure day with her students. It's definitely something she covers, and I think they would do well with the one-two punch of the fish activity and the

[34] 2/9/00 personal communication.
[35] 11/5/00 personal communication.
[36] 2/9/00 personal communication.

rabbits and grass [model]. I really enjoyed seeing how well those two activities complement each other. I'm also excited to try the function of the badges you showed me where the kids can graph how their own fish school changed over the course of the game. (1/9/01 email communication)

Yet, she feels she needs to train "her" teachers to ask questions about how technology fits into their curricula (even though this should be their main concern they don't know how to evaluate the technology or frame its use). If the teachers use technology at all, she finds that they tend to settle on one program that they are comfortable with. "It is my job to help them come up with a vision for technology."[37] She continues to look for an approach that would "integrate StarLogo into the upper grades that makes sense with what they classroom teachers do and fits in with [the] 80 minutes per week" that she sees her students.[38]

> The 7th and 8th grade science teacher is also excited to work with me and so we can integrate the use of models into her curriculum. Because I myself do not do much content-area instruction in science, next year I hope to collaborate with the science teacher on developing some models for her students to use. I also will work with the 6th grade teacher, who teaches biomes and population dynamics. I picture us using existing models to enable the students to explore predator-prey relationships and other factors that can affect biomes and food chains.
>
> Within my own classes, I will continue to introduce StarLogo as a programming tool so that students can continue to expand their understanding of technology and their relationship to it. (2/26/01 email communication)

In the long run, she wants to craft a coherent technology program that will be pervasive throughout her K-8 school. She wants a program that showcases the diverse ways that students can express themselves through technology.

In addition to expanding the modeling activities in her school, Cathy continues to build a network of colleagues outside of her school. In preparation for her NECC workshop, we invited her (along with a few other teachers from previous Workshops) to present to a group of independent school science teachers in California. Because of her work with students and teachers, she was invited to be a mentor at one of the StarLogo teacher Workshops this summer.

> I just wanted to say how much I enjoyed working with you three in L.A. I thought the Workshop was very valuable for the teachers who attended, and I certainly learned a lot that will help me when I present at NECC in June. I'd be curious to hear any comments the rest of you have about how things went, ups and downs, etc.
>
> My main impressions were that people loved the hands-on time and wish they'd had more of it; perhaps cutting down the virus activity a bit would have helped (although that did lay an important foundation for thinking about modeling in general). Eric and I have already talked about this, but it also seemed like the vast array of models to explore was overwhelming for some of the teachers (although it was a nice variety for others!) In general, I think things went very well and that people left with ideas and skills they can build on.
>
> Again, it was a pleasure working with you, and I'm looking forward to possible future collaborations. (3/19/01 email communication)

[37] 2/9/00 personal communication.
[38] 2/9/00 personal communication.

Cathy's story highlights how new ideas can spread and be a substrate for teacher-teacher communication and can lead to improvements in practice.

Shaping Change

As the variety of teachers' paths and choices suggests, many factors influence the likelihood that teachers will integrate modeling tools and ideas into their curricula. In the time that we have observed teachers using materials and methods from the Workshops, we have identified several patterns of teacher adoption, which are shaped by both individual and environmental factors. We have divided these factors into three categories: institutional, professional, and personal.

First, the level of intellectual and logistical support provided within teachers' professional institutions is a determining factor in the type of adoption teachers undertake. With sufficient institutional support, even teachers who are not "pioneers" are able to make notable changes in their practices. Without this support, some of the most motivated teachers can see their efforts thwarted. Specific issues that can bolster or frustrate teachers' efforts are the level of access to technology in school, the degree of support from principals and department chairs, the degree of flexibility and amount of preparation time built into teachers' schedules, and the extent to which their curricula are constrained by standards or other curricular guidelines. These institutional and organizational factors exerted a strong influence on the willingness and ability of the Workshop teachers to enact changes in their classes. In the case studies we observed some teachers, like Cathy and Carl, who were given tremendous latitude and support from their schools and others, like Julie and Noah, who encountered resistance and difficulties. Though every teacher is different, the climate in any given school is one indicator of the kinds and degrees of change that will be enabled and rewarded.

Second, teachers' past professional experience is another factor that influences their inclination and ability to enact change. Since all of the Workshop participants chose to attend the Adventures Workshop, they represent a biased sample of teachers who are more likely than average to want to alter or enhance their teaching through the use of technological tools. Yet, even within this set of teachers, there are relevant distinctions that influence the degree and kind of innovative ideas and technologies they use in class. These distinctions include the amount of teaching experience that they have, their past experiences with introducing innovations, and the knowledge and skills that they possess. We found that teachers who had been in the classroom for many years, like Julie and Noah, have often built up enough professional "capital" that they are afforded a high degree of autonomy by their superiors, positioning them to make and carry out changes in their own teaching. We also found that relatively inexperienced teachers, like Cathy, were often willing to try new things. These teachers are frequently looking for new ideas to fill out their curricula, and the combination of their enthusiasm and their inexperience with unsupportive superiors and entrenched bureaucracies makes them more likely to try new things without considering the potential negative repercussions. Similarly, a past history of attempting innovative classroom changes influences teachers' desires and abilities to integrate modeling tools and ideas (and likely also influenced teachers' inclinations to attend the Workshop in the first place). Frequently, teachers who had previously attempted changes in their classes and received criticism for their efforts were slightly slower to integrate modeling but still willing to try. On the one hand, these teachers know the pitfalls of introducing changes, which on the surface might make them less likely to try. On the other hand, knowing the pitfalls enables them to navigate the organizational landscape in order to maximize their results and minimize any damage to their professional standing. For instance, though Bea and Noah both had negative past experiences when they tried to make improvements in their courses, they were willing to integrate modeling tools and ideas, though they consciously worked to avoid criticism from their administrators. Finally, the teachers who come to our Workshops possess a wide variety of skills and knowledge. Those teachers who are reflective about their own knowledge and their own pedagogies were more likely to integrate modeling tools and ideas into their classes. Teachers like Sylvester, who are interested in new tools but less reflective about their own practices are rarely motivated or able to transform their classes.

Third, teachers' conceptions of themselves as educators and their roles in the larger education community also shape the effort that they are willing to expend to make changes in their practices. Though all teachers are charged with helping their students learn about the subjects they teach, some teachers also work hard to enrich their students' overall intellectual development. Those teachers who focus primarily on helping their students better understand specific content in their courses often adopt and institute small-scale changes. For example, Julie used StarLogo to augment her unit on predator-prey relationships. On the other hand, teachers who are more focused on empowering their students or broadening their students' general understanding are more likely to adopt modeling as a "powerful idea" for thinking about the world. Like Noah, these teachers are most apt to transform their courses in dramatic ways. Teachers' hopes and goals for education also inform the ways in which they choose to use modeling. Those teachers who want to be engaged with the larger educational community or who see constant improvement as part of their educational mission adapt modeling ideas and tools more extensively than those who focus mainly on the activities in their own classrooms. For teachers who want to make professional contribution to the overall betterment of education, modeling can be one platform for this activity. For instance, both Cathy and Carl used modeling as a vehicle for facilitating professional development activities for their peers. Such activities lead to local improvements in schools and the development of a widespread structure for supporting educational advances.

A Flexible Approach

We find that some teachers are attracted to model building because they are personally fascinated, others because it fills a perceived need; some because they are just looking for ways to improve their students' learning experiences, and yet others for all of these reasons and many more. The important thing is that our Workshops were flexible enough to accommodate teachers who wanted to use our materials in ways that fit their needs—ways that help them solve problems that they faced in their own teaching.

The stories of Noah, Carl, Julie, and Cathy capture just a few of the many ways that teachers opt to change their practices. For Noah, making changes across his curriculum was important—and possible. Noah and his students used modeling to engage in authentic scientific investigation and exploration. His school afforded him enough flexibility to alter his course substantially and enough time to put those changes in place, though he later encountered administrative backlash. In Carl's case, widespread change came much more slowly. Only after teaching modeling for a few years did he begin to consider how it might be fully integrated with other courses. And, only after he reconsidered his approach to modeling did his ability to promote it (both inside and outside of his school) flourish. Julie used her new knowledge of modeling to augment her existing practice. Adopting pieces of the modeling culture from the summer Workshop gave her students and her another way to understand patterns and processes in the world around them. Her initial success led to new possibilities with other teachers and prompted her to plan additional changes to her practice next year. For Cathy, the process of reaching out and developing a community helped her make decisions about how to change her own practice. Her experiences highlight the need for a supportive community both in school and at large. Such a community helps teachers enact local changes and provides a platform for building upon each other's successes.

Over several years of running the Adventures in Modeling Workshops, we have come to appreciate the need to validate and promote many pathways to changing practice. Rather than viewing some teachers' experiences as limited successes and others as 'the ideal integration of our modeling curriculum', it is important that we see each experience as another pathway to bringing modeling ideas into the classroom. Reform is not driven solely by individuals who push for large-scale transformations—it also proceeds step-by-step, over time. Reform is also not driven by researchers who dream up new technologies—it is driven by teachers who adopt tools and processes that address their own needs and those of their students. Given the unimaginable variety of classroom situations across the nation, we must expect improvements to manifest themselves in a wide variety of ways. Incremental paths to improvement are just as important and significant as swift transformations. Only when researchers begin to truly appreciate the tremendous variability in teachers' personal and institutional contexts will they be able to infuse new ideas into existing educational settings.

In the final chapter, we recap teachers' experiences in the Workshop and reflect on their uses of modeling in their classrooms. We explore how new tools can provide a platform for reconceiving and refining classroom practices; the importance of community, both in and out of school, for supporting and sustaining change; and the role that modeling can play in professional development.

8. Prospects for Change

By looking at the common themes that emerge from teachers' experiences both in the Workshops and in their schools, we are able to better understand the processes that teachers go through as they learn about new technologies, encounter alternative pedagogical strategies, and endeavor to modify their own practices. This chapter concludes with a look at how the creation of a modeling culture leads to a variety of changes in educational practice, reinforces the need for a community structure to support teachers, and provides new opportunities for teachers' professional development.

Classroom Reform

During the Workshop, we created a set of conditions in which a modeling culture could thrive. In Chapter 7, we explored some of the ways that teachers were willing and able to appropriate facets of that culture for use in their own classrooms. In observing when and how teachers decided to alter their practices, we learned several things about facilitating classroom reform. Perhaps most importantly, we were reminded that classroom reform must grow out of teachers' needs and abilities, not just out of reformers' desires for change.

The introduction of new technological tools and associated practices can support and encourage the difficult process of refining teaching practice. It is true that tools, like the modeling tools we used, can be a 'Trojan mouse' for classroom change, but not for many of the reasons often cited. New technologies don't open doors just because they enable teachers and students to teach and learn with new materials. New technologies hold potential for facilitating changes in classroom practice because as teachers learn about new technologies there is an opportunity for them to reconsider and reflect on their role in the processes of teaching and learning.

By including Activities and other non-computer entries to modeling, we not only provided teachers with different ways to explore similar problems, we also implicitly validated a pedagogical strategy that many of them already employed. The inclusion of different kinds of modeling in the Workshop also validates the multiple paths to integration that teachers enact. Teachers saw that there were ways to integrate thinking through modeling, and some of those approaches were very similar to their existing practices. Just as we don't view Activities as 'second-class citizens' in our Workshops, we legitimately value their inclusion by teachers as important additions to teaching practice. The wide variety of classroom and school landscapes suggests a wide variety of potential classroom changes. Because we could not know a priori what size hole our round peg of innovation might be destined for, we created a flexible curriculum that teachers could adopt to fit their needs.

Like teacher professional development, changing classroom practices is a lengthy process and not one that we want to end six months after the Workshop. Our longer term successes with teachers from prior Workshops, and the early indications that many teachers from the 2000 Workshop are continuing their modeling pursuits both in and out of their schools gives us a strong hope that the Adventures' strategies hold promise for facilitating lasting classroom changes.

The Role of Community

Of course, isolated change is both difficult and massively under-leveraged. Perhaps one of the most significant contributions of the Adventures in Modeling Project is that it highlights the critical importance of a community of practice. In education, this community should function to improve practice, by giving teachers the support they need to enact change, and to provide a forum for teachers to share their successes and build off of their peers' experiences. We found that our teachers required two kinds of community when they returned to school.

Teachers need a local community to serve as a sounding board for proposed improvements in practice and provide ideas, inspiration, and support when the rubber meets the road. Like the community at the Workshop, this local community is a setting for exchanging ideas, challenging understandings, and debugging technical and logistical troubles. The local community provides teachers with on-going, contextually relevant opportunities to interact with other teachers and reflect on their own practice.

But this local level of support is not the only important function of community. Community must also provide a larger outlet for sharing successes, gaining recognition, and receiving feedback. We found that many of the Workshop participants thrived on presenting their projects to others, and that the processes of articulating the changes they made in their classes and describing the intellectual issues with which they grappled helped them to further refine their teaching practices. When teachers go outside of their immediate community to present and engage with other people around modeling issues, they receive external validation (or criticism) for their efforts and they begin to see how their individual efforts contribute to a larger cause. Participation in this larger community is professionally satisfying and often missing from teachers' academic lives.

As in the scientific community, this combination of local and larger communities is the key to individual achievement, group progress, and the advancement of knowledge. Building a community of practice is a good way to get people engaged in authentic scientific practice, both in terms of the content of science and the process of exchanging and building knowledge. As a testimony to teachers' willingness to contribute to and draw upon a strong community of practice, many of our Workshop teachers asked to return for second and third summers to refine their own skills and help mentor the next group of teachers.

Professional Development

While most participants come to the Adventures in Modeling Workshops with the intention of bringing new tools into their classes, many also leave with new pedagogical and scientific understandings. Though we did not initially focus on developing these capabilities, several aspects of the Workshop structure support this aspect of professional development.

The Adventures in Modeling Workshops enable teachers to better understand the activities of authentic science practice. During the Workshop, they create artifacts that make their understandings of systems explicit, they engage in iterative investigations, they modify their models based on new understandings, and they collaborate with a diverse group of peers. Perhaps most notably they gain experience in three fundamental, but often suppressed, features of scientific practice—they engage in community knowledge construction, they participate in a culture that values exploration at the limits of what is known, and they learn to connect their own personal experiences to their understandings of the world.

Unfortunately, and somewhat ironically, teachers work in a culture that values knowing but not always the messy learning process that results in knowing. Modeling, especially the kind of modeling that we advocate, can shed light on counter-intuitive processes and patterns in the world. Designing and building models can help people to see that the assumptions that they bring to a problem are not always correct. In the modeling culture that we create, it is acceptable to not know something and it is crucial to reveal the learning process.

Like many people, teachers tend to believe that science and mathematics are focused on objective truth. Throughout the Workshops, we work with teachers to legitimize the strategy of making connections between personal experience and patterns and processes in the world around them. They become interested in problems for the sake of exploration as well as for their application to subsequent teaching situations. By engaging people in a modeling culture, we enable them to think and learn as scientists. We change participants' conceptions of scientific practice by allowing them to work and learn in a culture of scientific discovery.

Achieving Success

Through the Adventures in Modeling Project we created a set of materials and a pedagogical structure that facilitates the development of a modeling culture among teachers. We then worked with those same teachers to understand how and when they would aim to recreate some aspects of that culture in their own classrooms. This research shows how participation in a modeling culture contributes to a scientific way of thinking, for both teachers and their students, and helps bring authentic scientific exploration to teachers and their students. The results of this project provide one example that educational researchers, technology developers, and public policy makers can use to evaluate the potential that new ideas and tools hold for facilitating lasting change in America's classrooms.

Bibliography

Ackermann, E. (1996). Perspective-taking and object construction: Two keys to learning. In Y. Kafai & M. Resnick (Eds.), *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World* (pp. 25-35). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Axtell, R. (1997). *Three distinct uses of agent-based computational models in the social sciences*. Washington, D.C.: Brookings Institution.

Ball, D., & Cohen, D. (1996). Reform by the book: What is--or what might be--the role of curriculum materials in teacher learning and instructional reform. *Educational Researcher, 25*(9), 6-8, 14.

Bedini, S. (1964). The Role of Automata in the History of Technology, *Technology and Culture* (pp. 24-42): University of Chicago Press.

Booth Sweeney, L., & Meadows, D. (1995, 1996). *The Systems Thinking Playbook: Exercises to stretch and build learning and systems thinking capabilities*. Durham, NH: Laboratory for Interactive Learning.

Borovoy, R., McDonald, M., Martin, F., & Resnick, M. (1996). Things that blink: Computationally augmented name tags. *IBM Systems Journal, 35*(3), 488-495.

Brehmer, B. (1980). In one word: Not from experience. *Acta Psychologica, 45*, 223-241.

Brown, A., & Campione, J. (1990). Interactive learning environments and the teaching of science and mathematics. In M. Gardner, J. Greeno, F. Reif, A. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a Scientific Practice of Science Education* (pp. 111-140). Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*, 32-42.

Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41*(10), 1123-1130.

Cohen, D. (1996). Standards-based school reform: Policy, practice, and performance. In H. Ladd (Ed.), *Holding Schools Accountable* (pp. 99-127). Washington, D.C.: Brookings Institution.

Colella, V. (1998). *Participatory Simulations: Building Collaborative Understanding through Immersive Dynamic Modeling.* Unpublished masters thesis, MIT, Cambridge, MA.

Colella, V. (December, 1999). *Exploring Immersive CSCL through Participatory Simulations.* Paper presented at the Computer Supported Collaborative Learning Conference (CSCL), Palo Alto, CA.

Colella, V. (2000). Participatory Simulations: Building collaborative understanding through immersive dynamic modeling. *Journal of the Learning Sciences, 9*(4), 471-500.

Colella, V. (in press). Participatory Simulations: Building collaborative understanding through immersive dynamic modeling. In T. Koschmann, R. Hall, & N. Miyake (Eds.), *CSCL2: Carrying Forward the Conversation*. Mahwah, NJ: Lawrence Erlbaum, Assoc.

Colella, V., Borovoy, R., & Resnick, M. (1998a). *Participatory Simulations: Adding a thin layer of computation to face-to-face collaborative inquiry.* Paper presented at the American Educational Research Association (AERA) Annual Meeting, San Diego, CA.

Colella, V., Borovoy, R., & Resnick, M. (1998b). *Participatory Simulations: Using computational objects to learn about dynamic systems.* Paper presented at CHI '98, Los Angeles, CA.

Colella, V., Klopfer, E., & Resnick, M. (1999). StarLogo Community of Learners Workshop. *Logo Exchange, Journal of the ISTE Special Interest Group for Logo-Using Educators, 17*(2).
Colella, V., Klopfer, E., & Resnick, M. (2001). *Adventures in Modeling: Exploring Complex, Dynamic Systems with StarLogo*. New York: Teachers College Press.
Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, Learning, and Instruction* . Hillsdale, NJ: Lawrence Erlbaum, Assoc.
Confrey, J., & Doerr, H. (1994). Student modelers. *Interactive Learning Environments, 4*(3), 199-217.
Coppola, E. (2000). *Teachers learning in school: How teachers learn to use computers for constructivist teaching and how the school's organizational culture can support them.* Unpublished doctoral thesis, Harvard University, Cambridge, MA.
Cuban, L. (1986). *Teachers and Machines: The Classroom Use of Technology Since 1920*. New York: Teachers College Press.
Cuban, L. (1993). *How Teachers Taught: Constancy and Change in American Classrooms 1890-1990*. New York: Teachers College Press.
Curtis, H., & Barnes, N. (Eds.). (1989). *Biology* (Fifth ed.). New York: Worth Publishers, Inc.
Dewey, J. (1938/1998). The pattern of inquiry. In L. Hickman & T. Alexander (Eds.), *The Essential Dewey: Volume 2: Ethics, Logic, Psychology* (pp. 169-179). Bloomington: Indiana University Press.
Dewey, J. (1988). Experience and Education. In J. Boydston (Ed.), *John Dewey: The Later Works, 1925-1953* (Vol. 13, pp. 1-62). Carbondale, IL: Southern Illinois University Press.
Dimaraki, E., Black, J., & Brown, M. (1988). What pedagogy for the age of abundant information? Lessons from Archaeotype. *Educational Media International, September*, 181-185.
diSessa, A. (1986). Artificial worlds and real experience. *Instructional Science, 14*, 207-227.
diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the Computer Age* (pp. 49-70). Hillsdale, NJ: Lawrence Erlbaum, Assoc.
diSessa, A., Hammer, D., Sherin, B., & Kolpakowski, T. (1991). Inventing graphing: Meta-representational expertise in children. *The Journal of Mathematical Behavior, 10*, 117-160.
Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.
Duckworth, E., Easley, J., Hawkins, D., & Henriques, A. (1990). *Science Education: A Minds-On Approach for the Elementary School Years*. Mahwah, NJ: Lawrence Erlbaum, Assoc.
Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. Sternberg & J. Davidson (Eds.), *The Nature of Insight*. Cambridge, MA: MIT Press.
Edelson, D. (1997). Realizing authentic science learning through the adaptation of science practice. In K. Tobin & B. Fraser (Eds.), *International Handbook of Science Education*. Dordrecht, NL: Kluwer.
Edelson, D., Gordin, D., & Pea, R. (March 1997). *Creating science learning tools from experts' investigation tools.* Paper presented at the National Association for Research in Science Teaching (NARST) Annual Meeting, Oak Brook, IL.

Edelson, D., & O'Neill, D. (1994). *The CoVis collaboratory notebook: Computer support for scientific inquiry.* Paper presented at the American Educational Research Association (AERA) Annual Meeting.
The Edison Project. (1999). *Annual Report on School Performance.*
Elmore, R. (1993). *The development and implementation of large-scale curriculum reforms.* Cambridge, MA: Harvard University and the Consortium for Policy Research in Education.
Elmore, R. (1996). Getting to scale with good educational practice. *Harvard Educational Review, 66*(1), 1-26.
Elmore, R., Peterson, P., & McCarthey, S. (1996). *Restructuring in the Classroom: Teaching, Learning, and School Organization.* San Francisco, CA: Jossey-Bass.
Epstein, J., & Axtell, R. (1996). *Growing Artificial Societies: Social Science from the Bottom Up.* Washington D.C.: Brookings Institution Press.
Feurzeig, W., & Roberts, N. (Eds.). (1999). *Modeling and Simulation in Precollege Science and Mathematics Education.* New York: Springer-Verlag.
Fullan, M. (1995). The school as a learning organization: Distant dreams. *Theory into Practice, 34*(4), 230-235.
Fulton, K., Feldman, A., Wasser, J., Spitzer, W., Rubin, A., McNamara, E., Grant, C., Porter, B., & McConachie, M. (1996). *Technology Infusion and School Change: Perspectives and Practices* (Research Monograph). Cambridge, MA: Model Schools Partnership, TERC.
Gardner, H. (1983). *Frames of Mind: The Theory of Multiple Intelligences.* New York: Basic Books.
Gardner, H. (1991). *The Unschooled Mind: How Children Think and How Schools Should Teach.* New York: Basic Books.
Gardner, M., Greeno, J., Reif, F., Schoenfeld, A., diSessa, A., & Stage, A. (Eds.). (1990). *Toward a Scientific Practice of Science Education.* Hillsdale, NJ: Lawrence Erlbaum, Assoc.
Gomez, L., Burgess, C., Clay-Chambers, J., Marx, R., Soloway, E., & Schank, R. (2000). *Center for Learning Technologies in Urban Schools (LeTUS)* (http://www.ehr.nsf.gov/lis/gomez.htm). Evanston, IL
Ann Arbor, MI: Northwestern University, University of Michigan at Ann Arbor, Chicago Urban Systemic Initiative, Detroit Urban Systemic Initiative.
Hancock, C., Kaput, J., & Goldsmith, L. (1992). Authentic inquiry with data: Critical barriers to classroom implementation. *Educational Psychologist.*
Hawkins, D. (1965). Messing about in science. *Science and Children, 2*(5).
Hawkins, J., & Pea, R. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24*(4), 291-307.
Healy, J. (1998). *Failure to Connect: How Computers Affect our Children's Minds--for Better and Worse.* New York: Simon & Schuster.
Hirsch, E. J. (1987). *Cultural Literacy: What Every American Needs to Know.* Boston, MA: Houghton Mifflin Co.
Hirsch, E. J. (1996). *The Schools We Need: And Why We Don't Have Them.* New York: Doubleday.
Hut, P., & Sussman, G. (1987). Advanced computing for science. *Scientific American, 257*(4), 145-153.

Judson, O. (1994). The rise of individual-based modeling in ecology. *Trends in Ecology and Evolution, 9*(1), 9-14.

Kafai, Y., & Ching, C. (1998). *Talking science through design: Children's science discourse within software design activities.* Paper presented at the International Conference of the Learning Sciences (ICLS), Atlanta, GA.

Kafai, Y., & Resnick, M. (Eds.). (1996). *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World.* Mahwah, NJ: Lawrence Erlbaum, Assoc.

Keller, E. F. (1983). *A Feeling for the Organism: The Life and Work of Barbara McClintock.* San Francisco, CA: W. H. Freeman.

Kleiner, A., & Roth, G. (1997). How to make experience your company's best teacher. *Harvard Business Review, 75*(5), 172-177.

Klopfer, E. (2000). *Building understanding of models through simulation construction.* Paper presented at the American Educational Research Association (AERA) Annual Meeting, New Orleans, LA.

Klopfer, E., & Colella, V. (December, 1999). *Structuring Collaboration in Workshops and Classrooms: The StarLogo Community of Learners.* Paper presented at the Computer Supported Collaborative Learning Conference (CSCL), Palo Alto, CA.

Klopfer, E., & Colella, V. (2000). *Modeling for understanding.* Paper presented at the Society for Information Technology and Teacher Education (SITE) Conference, San Diego, CA.

Knapp, M. (1997). Between systemic reforms and the mathematics and science classroom: The dynamics of innovation, implementation, and professional learning. *Review of Educational Research, 67*(2), 227-266.

Kolodner, J., Crismond, D., Gray, J., Holbrook, J., & Puntambekar, S. (1998). *Learning by design from theory to practice.* Paper presented at the International Conference of the Learning Sciences (ICLS), Atlanta, GA.

Kolodner, J., & Guzdial, M. (1996). Effects with and of CSCL: Tracking learning in a new paradigm. In T. Koschmann (Ed.), *CSCL: Theory and Practice of an Emerging Paradigm* (pp. 307-320). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Kolodner, J., & Nagel, K. (1999). *The design discussion area: A collaborative learning tool in support of learning from problem-solving and design activities.* Paper presented at the Computer Supported Collaborative Learning (CSCL), Palo Alto, CA.

Koschmann, T. (1993). Using technology to assist in realizing effective learning and instruction: A principled approach to the use of computers in collaborative learning. *Journal of the Learning Sciences, 3*(3).

Koschmann, T. (Ed.). (1996a). *CSCL: Theory and Practice of an Emerging Paradigm.* Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Koschmann, T. (1996b). Technology and education reform. *Interactive Learning Environments.*

Kraut, R., Egido, C., & Galegher, J. (1990). Patterns of contact and communication in scientific research collaboration. In J. Galegher & R. Kraut (Eds.), *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work* (pp. 149-171). Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Kuhn, T. (1962). *The Structure of Scientific Revolutions.* Chicago, IL: University of Chicago Press.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers Through Society.* Cambridge, MA: Harvard University Press.

Lave, J. (1991). Situated learning in communities of practice. In L. Resnick, J. Levine, & T. Teasley (Eds.), *Perspectives on Socially Shared Cognition*. Washington DC: American Psychological Association.

Lehrer, R., Horvath, J., & Schauble, L. (1994). Developing model-based reasoning. *Interactive Learning Environments, 4*(3), 218-232.

Lehrer, R., & Romberg, T. (1996). Exploring children's data modeling. *Cognition and Instruction, 14*(1).

Linn, M., & Hsi, S. (2000). *Computers, Teachers, Peers: Science Learning Partners*. Mahwah, NJ: Lawrence Erlbaum, Assoc.

Linn, M., & Slotta, J. (2000). *WISE: The Web-based Integrated Science Environment* (http://wise.berkeley.edu/WISE/pages/research.php). Berkeley, CA: UC Berkeley.

Lunetta, V. (1990). Cooperative learning in science, mathematics, and computer problem solving. In M. Gardner, J. Greeno, F. Reif, A. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a Scientific Practice of Science Education* (pp. 235-249). Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Mathworks. (1994). MatLab. Natick, MA.

Maxis. (1989). SimCity. Orinda, CA: Electronic Arts.

Maxis. (2000). the Sims. Orinda, CA: Electronic Arts.

McNeil, L. (2000). *Contradictions of School Reform: Educational Costs of Standardized Testing*. New York: Routledge.

Meadows, D. (1986). *FishBanks, LTD.* (http://www.unh.edu/ipssr/index.html/ipssr/lab/fishbank.html). Durham, NH: Institute for Policy and Social Science Research.

Means, B. (1998). *Models and Prospects for Bringing Technology- Supported Education Reform to Scale.* Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Means, B., & Golan, S. (1998). *Transforming Teaching and Learning with Multimedia Technology*. Menlo Park, CA: SRI International.

Microprose. (1996). Civilization. Beverly, MA: Hasbro Interactive.

Minsky, M. (1985). *The Society of Mind*. New York: Simon & Schuster.

National Committee on Science Education Standards and Assessment, National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

National Council of Teachers of Mathematics. (1998). *NCTM Principles and Standards for School Mathematics*. Reston, VA.

Newman, D. (1995). Technology's role in restructuring for collaborative learning. In C. O'Malley (Ed.), *Computer Supported Collaborative Learning* (Vol. 128). Berlin: Springer-Verlag.

Norris, C., Topp, N., & Soloway, E. (2000). *SnapShot Survey* (http://snapshotsurvey.org/index.html).

Oppenheimer, T. (July, 1997). The computer delusion. *The Atlantic Monthly*.

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books, Inc.

Papert, S. (1990). *A critique of technocentrism in thinking about the school of the future* (E & L Memo No. 2). Cambridge, MA: MIT Media Lab.

Papert, S. (1993). *The Children's Machine: Rethinking School in the Age of the Computer*. New York: BasicBooks.

Papert, S., & Resnick, M. (1993). *Technological fluency and the representation of knowledge* : Proposal to the National Science Foundation.

Postman, N. (1996). *The End of Education: Redefining the Value of School*. New York: Vintage Books.

Project 2061, A.A.A.S. (1993). *Benchmarks for Scientific Literacy*. Oxford: Oxford University Press.

Puntambekar, S., & Kolodner, J. (1998). *The design diary: Development of a tool to support students learning science by design*. Paper presented at the International Conference of the Learning Sciences (ICLS), Atlanta, GA.

Ravitch, D. (1983). *The Troubled Crusade: American Education, 1945-1980*. New York: Basic Books.

Reif, F. (1990). Instructional design. In M. Gardner, J. Greeno, F. Reif, A. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a Scientific Practice of Science Education* (pp. 87-91). Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Resnick, L. (1987). Learning in school and out. *Educational Researcher, 16*(9).

Resnick, M. (1994). *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds*. Cambridge, MA: MIT Press.

Resnick, M. (1996). New paradigms for computing, new paradigms for thinking. In Y. Kafai & M. Resnick (Eds.), *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World* (pp. 255-267). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Resnick, M. (2001). Closing the fluency gap. *Communications of the ACM, 44*(3), 144-145.

Resnick, M., Bruckman, A., & Martin, F. (1996). Pianos not stereos: Creating computational construction kits. *Interactions, 3*(6), Sept./Oct.

Resnick, M., Rusk, N., & Cooke, S. (1999). The Computer Clubhouse: Technological fluency in the inner city. In D. Schon, B. Sanyal, & W. Mitchell (Eds.), *High Technology and Low-Income Communities: Prospects for the Positive Use of Advanced Information Technology*. Cambridge, MA: MIT Press.

Resnick, M., & Wilensky, U. (1993). *Beyond the deterministic, centralized mindsets: New thinking for new sciences*. Paper presented at the American Educational Research Association (AERA) Annual Meeting, Atlanta, GA.

Resnick, M., & Wilensky, U. (1995). *New thinking for new sciences: Constructionist approaches for exploring complexity*. Paper presented at the American Educational Research Association (AERA) Annual Meeting, San Francisco, CA.

Resnick, M., & Wilensky, U. (1998). Diving into complexity: Developing probabilistic decentralized thinking through role-playing activities. *The Journal of the Learning Sciences, 7*(2), 153-172.

Roberts, N., Anderson, D., Deal, R., Garet, M., & Shaffer, W. (1983). *Introduction to Computer Simulation: A System Dynamics Modeling Approach*. Reading, MA: Addison-Wesley.

Rogoff, B. (1994). Developing understanding of the idea of communities of learners. *Mind, Culture and Activity, 1*(4), 209-229.

Roschelle, J. (1992). Learning by collaborating: convergent conceptual change. *The Journal of the Learning Sciences, 2*(3), 235-276.

Roschelle, J. (1996). Learning by collaborating: Convergent conceptual change. In T. Koschmann (Ed.), *CSCL: Theory and Practice of an Emerging Paradigm* (pp. 209-248). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Roughgarden, J., Bergman, A., Shafir, S., & Taylor, C. (1996). Adaptive Computation in Ecology and Evolution: A Guide for Future Research. In R. Belew & M. Mitchell (Eds.), *Adaptive Individuals in Evolving Populations: Models and Algorithms* (Vol. Proceedings Volume XXVI Santa Fe Institute Studies in the Science of Complexity, pp. 25-30). Reading, MA: Addison-Wesley.

Scardamalia, M., & Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.), *CSCL: Theory and Practice of an Emerging Paradigm* (pp. 249-268). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Schoenfeld, A. (1990). GRAPHER: A case study of educational technology, research, and development. In M. Gardner, J. Greeno, F. Reif, A. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a Scientific Practice of Science Education* (pp. 281-300). Hillsdale, NJ: Lawrence Erlbaum, Assoc.

Senge, P., Roberts, C., Ross, R., Smith, B., & Kleiner, A. (1994). *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization.* New York: Currency Doubleday.

Shaffer, D. (1998). *The pedagogy of the digital studio: Learning through collaboration, expression and construction.* Paper presented at the International Conference of the Learning Sciences (ICLS), Atlanta, GA.

Shaw, D. (1997). *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States* . Washington, D.C.: President's Committee of Advisors on Science and Technology (PCAST).

Sizer, T. (1984). *Horace's Compromise.* Boston, MA: Houghton Mifflin Company.

Smith, J., diSessa, A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences, 3*(2), 115-163.

Soloway, E., Pryor, A., Krajcik, J., Jackson, S., Stratford, S., Wisnudel, M., & Klein, J. (1997). ScienceWare's Model-It: Technology to support authentic science inquiry. *T.H.E. Journal*, 54-56.

Sterman, J. (1994). Learning in and about complex systems. *System Dynamics Review, 10*(2-3), 291-330.

Stigler, J., & Hiebert, J. (1999). *The Teaching Gap: Best Ideas from the World's Teachers for Improving Education in the Classroom*: Free Press.

Talsma, V. (2000). *Scientific understandings revealed by students' computer models of a stream: A trickle or a flood?* Paper presented at the International Conference of the Learning Sciences (ICLS), Ann Arbor, MI.

Taylor, J., Noll, R., Klopfer, E., & Colella, V. (March, 2001). *Creating and analyzing models in StarLogo: A secondary science approach.* Paper presented at the National Association for Research in Science Teaching (NARST) Annual Meeting, St. Louis, MO.

Tharp, R., & Gallimore, R. (1991). *Rousing Minds to Life: Teaching, Learning, and Schooling in Social Context.* Cambridge: Cambridge University Press.

Turkle, S., & Papert, S. (1992). Epistemological pluralism and the revaluation of the concrete. *Journal of Mathematical Behavior, 11*, 3-33.

Tyack, D., & Cuban, L. (1995). *Tinkering Toward Utopia: A Century of Public School Reform.* Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (Ed.). (1978). *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University.

Wade, N. (February 12, 2001). Long-held beliefs are challenged by new human genome analysis. *The New York Times*.

Wertsch, J. (1998). *Mind as Action*. New York: Oxford University Press.

White, B. (1993). ThinkerTools: Causal models, conceptual change, and science education. *Cognition and Instruction, 10*(1), 1-100.

Wilensky, U. (1993). *Connected mathematics: Building concrete relationships with mathematical knowledge.* Unpublished doctoral dissertation, MIT Media Laboratory, Cambridge, MA.

Wilensky, U. (1995). Paradox, programming, and learning probability: A case study in a connected mathematics framework. *Journal of Mathematical Behavior, 14*, 253-280.

Wilensky, U. (1996). Making sense of probability through paradox and programming. In Y. Kafai & M. Resnick (Eds.), *Constructionism in Practice: Designing, Thinking, and Learning in a Digital World* (pp. 269-296). Mahwah, NJ: Lawrence Erlbaum, Assoc.

Wilensky, U. (in press). ConnectedScience: Learning Biology through Constructing and Testing Computational Theories—an Embodied Modeling Approach. *InterJournal of Complex Systems*, 1-12.

Wilensky, U., & Stroup, W. (April, 1999). *Learning through Participatory Simulations: Network-based design for systems learning in classrooms.* Paper presented at the American Educational Research Association (AERA) Annual Meeting, Montreal, Canada.

Wilson, W. (1998). Resolving discrepancies between deterministic population models and individual-based simulations. *American Naturalist, 151*(2), 116-134.

Appendix A. Agenda for the Adventures in Modeling Workshop

	Monday 17th	Tuesday 18th	Wednesday 19th	Thursday 20th	Friday 21st
9am	27 Blind Mice	Model Survey	Finish Challenge 3	Finish Challenge 4 and group exchange	Work on Challenge 5
9:30am	Introductions	Pixilated Paths	Pinup Challenge 3	Discussion on technology in the classroom & workshop feedback	10:00 Desk Crits on Challenge 5
10:45am	Break	Break	Break	Break	Break
11:00am	Challenge 1 & Intro to Challenge 2	Challenge 3	Challenge 4	Intro to Challenge 5 - Work on Challenge 5	Work on Challenge 5 11:20ish Brainstorming and Pinup
Noon	Lunch	Lunch	Lunch	Lunch	Lunch & Model Discussion
1pm	Challenge 2	Challenge 3	Challenge 4 desk crits and work	Predator-Prey badge activity	Visit to the Virtual Fishtank
2pm	Challenge 2 Pinup		Humanboids		
3pm	Round of Applause	2:30 Paper Catchers and Penny Growth	Challenge 4 work	Work on Challenge 5	
			Group dinner		

	Monday 24th	**Tuesday 25th**	**Wednesday 26th**	**Thursday 27th**
9am	9:15 Pinup Challenge 5	Finish Challenge 6	Work on Challenges	Final Projects
10:00am	Introduce Challenge 6		9:30 Progress Reports	
10:45am	Break	10:15am Break	Break	Break
11:00am	Work on Challenge 6	10:30 Pinup Challenge 6 & Introduce Challenge 8	Optional Session on Challenges 9 & 10	Final Projects
Noon	Lunch	Lunch	Lunch	Lunch
1pm	Foraging Frenzy (w/ a little idea model discussion)	Challenge 8	Final Projects	Move to Bartos Theater
2:30pm	Challenge 6	Virus Badges		1:30pm Final Review With guest reviewers and open to the MIT community
3pm				Workshop feedback
4pm		Get Together and Lab Open Until 5:30 5:30 BBQ		

Appendix B. StarLogo Community of Learners Teacher Survey

Adapted from the SnapShot Survey (Norris, Topp, & Soloway, 2000).

1. What best describes your current position?

Teacher	Principal or Assistant Principal
Professor or Instructor	Curriculum Coordinator
Media Specialist	Support Staff
Director/Supervisor/Other	Technology Coordinator (no teaching)
Superintendent or Assistant Superintendent	Other

2. If you are a teacher, what best describes your assignment?

Elementary or Self-contained	Language Arts
Math	Foreign Language
Social Studies	Science
Family and Consumer Science	Industrial Technology
Business	Music
PE/Health	Art
Special Education	Gifted and Talented
Computer Specialist	N/A

3. What best describes your grade level assignment?

   PreK-K 1-3 4-6 7-8 9-12 K-6 K-12 7-12 Post-secondary None

4. What is your degree status at this time?

   BA/BS BA/BS+15 Masters Masters+15 Doctorate

5. How many years have you worked in education?

   1-5 yrs 6-10 yrs 11-15 yrs 16-20 yrs more than 20 yrs

6. What is your gender?

   male female

7. When my students use the computers for my course assignments:
(Strongly Disagree Disagree No Opinion Agree Strongly Agree)

   Students create products that show higher levels of learning
   There are more discipline problems in my room
   Students are more motivated
   It has a positive impact on my students' learning
   Students increase their use of a variety of resources (books, periodicals, interviews, etc.)
   The role of the teacher becomes more of a guide or coach
   Students often get sidetracked
   Students become more responsible for their learning
   Students collaborate more with each other
   The technology promotes creativity and exploration

8. Rate your principal's support of the use of computers with your students:
Strongly discourages Discourages Neutral Encourages Strongly encourages

9. What is the availability of an Internet-connected computer for your use at home?
An available computer is convenient An available computer is not convenient There is no computer available

10. What are the reasons you may not have chosen to use curricular-based software with your students? Not a Factor Somewhat Influential Most Influential
My students do not have enough access to computers
The available software is too difficult to use
The available software is of little value in my classes
Appropriate software is not available
Appropriate software is too difficult to obtain

11. Which of the following would help you to make technology an integral part of your school or classroom's curricular activities?
Please use the numbers 1-5 where 1 indicates a less urgent need and 5 indicates a more urgent need.
Need more time to learn to use computers and the Internet
Need more time to change the curriculum to better incorporate the technology
Need more training to use technology
Need more training with curriculum and pedagogy that integrates technology
Need access to more computers for my students
Need more access to the Internet for my students
Need more software that is curricular-based
Need more technical support to keep the computers working
Need more opportunities to work with colleagues to become more proficient using technology-enhanced curriculum units
Need more compelling reasons why I should incorporate technology into the classroom
Need faster access to the Internet for my students
Need access to faster, more powerful computers for my students

12. Rate the support of your students' parents toward the use of computers in your classes.
Strongly discourage Discourage Neutral Encourage Strongly encourage

13. What is the availability of an Internet-connected computer for your use at school?
An available computer is convenient An available computer is not convenient There is no computer available

14. Please indicate the number of typical (or average) minutes PER WEEK that:
(zero less than 15 15-45 46-90 more than 90)
You survey software for use in your classes
You spend time preparing to use technology in your classes
You surf the Internet to find classroom resources

You use a computer for record keeping or other administrative tasks
You use email to communicate with parents
You use email to communicate with other faculty or staff members
A typical student would use a computer at school
A typical student would use a computer in your class

15. What is the availability of computers for your STUDENTS in your classroom?
0 Computers 1 Computer 2-5 Computers 5-10 Computers More than 10 Computers

16. Rate yourself on the following:
I feel comfortable with designing lessons that integrate technology
I feel comfortable with authoring web pages
I feel comfortable with designing lessons that reflect district or national curriculum standards
I feel comfortable with designing lessons that integrate more than one discipline
I feel comfortable customizing software to meet my classroom needs
I feel comfortable with running classes that integrate technology

17. Complete this sentence: "With respect to using computers, I feel I...
am less skilled than my students."
have about the same skill level as my students."
am more skilled than my students."

18. What is the availability of a networked computer lab for your students?
Never Seldom 1 time per week 2 times per week 3 or more times per week

19. Please indicate your level of agreement with the following statements:
I believe that electronic media will replace textbooks within 5 years
I believe that the role of schools will be dramatically changed because of technology within 5 years
I believe that the role of the teacher will be dramatically changed because of technology within 5 years
I believe that I am a better teacher with technology
I believe that having my students use curricular-based software for a classroom assignment is time well spent

20. Which of the following types of software are used in your classroom?
Word processors (e.g., Microsoft Word, ClarisWorks, AppleWorks)
Office Productivity Tools: Spreadsheets (e.g., Excel, ClarisWorks) or Databases (e.g., FileMaker, ClarisWorks) or Presentation programs (e.g., PowerPoint, ClarisWorks)
Tools (e.g., KidPix, Inspiration, HyperStudio)
Non-curricular Software (e.g., Solitaire, PacMan)
Curricular-based Software (e.g., Geometer's Sketchpad; Stella; Interactive Physics; Adam; Logal; Choices, Choices; Oregon Trail)
Teacher-developed computer activities

21. Please list any curricular-based software that you use:

22. How have you used technology in your classroom this year (pick your favorite)?
Please give the following information:

Topic
Course
Grade level
Resources needed
Software Title
Short activity description

23. Where do you get information about teaching with technology?

Conferences
Research Journals
Peers/Colleagues
School Resource People (e.g. tech coordinator, curric coordinator, media specialist)
Teacher Magazines
Internet Websites
In-District Training
Your Own Reading and Exploration
Your Students
Consultants or Trainers

24. Please indicate your level of agreement with the following statements:

Telephone service in my classroom has been educationally useful
Cable television in my classroom has been educationally useful
The transition to incorporating technology into the district has been handled in a professional and effective manner
I believe that in the coming school year I will be able to use the new technologies to benefit my students
I would like to see locally developed (e.g., teacher or student created) educational materials distributed online
My students have benefited from the introduction of newer technologies to the classroom

25. How many years have you used computers in your classroom?

0 yrs 1-3 yrs 3-5 yrs 6-10 yrs more than 10 yrs

26. Please share your thoughts and expectations about the StarLogo workshop.

How did you find out about the StarLogo workshop?
What most influenced your decision to attend?
What are you most looking forward to in the next two weeks?
What do you anticipate will be your biggest challenge during the workshop?
Do you have any concerns about the workshop?
How do you anticipate applying ideas from the workshop in your classes?
How do you intend to integrate StarLogo in your curricula?

Appendix C: Workshop Wrap-Up and Evaluation

Did you feel that the Challenges were an effective way of learning about StarLogo? Why or why not? What changes would you make to the Challenges?

Did the Challenges increase your understanding of modeling and simulations in general? If so, how?

How did the off computer activities affect your understanding of modeling and simulations?

Were there particular activities that you enjoyed or found effective? What were they and what were their highlights?

Were there particular activities that need improvement or should be left out? Which ones?

Were the presentations of projects (pinups) by your colleagues useful?

Were the desk-crits (small group sharing sessions) useful?

How did working in small groups (and changing groups) impact your learning of StarLogo? Your overall experience in the workshop?

Did you feel that the workshop facilitators were helpful to you? Describe any positive or negative experiences.

Did you feel that the overall structure of the workshop worked well? Why or why not?

How did the workshop impact your overall understanding of modeling and simulation issues?

What are some qualities of a good model?

How did the workshop impact your overall understanding of the scientific method and scientific experimentation?

Did the workshop adequately address curricular issues and classroom implementation?

Do you plan to use any activities in your classes next fall? If so, please tell us which ones and why you might use them.

Do you plan on incorporating StarLogo into your classes next fall? If so, please tell us how you are currently thinking of using it.

What was your overall opinion of the workshop? Did it meet your expectations?