Final Report for NSF Grant DUE-9972486 (CCLI Program)[1]

An Inquiry-Based Simulation Learning Environment for the Ecology of Forest Growth

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1 Executive Summary

The project "An Inquiry-Based Simulation Learning Environment for the Ecology of Forest Growth" consisted of three main stages of approximately one year each: software development, curriculum development, and classroom implementation. The software development included two products: "black box" and "glass box" versions of a learning environment in the domain of forest ecology called "SimForest" (i.e. SimForest-B and SimForest-G). The glass box version allows students to "open up," inspect, and modify the underlying mathematical model driving the simulation, whereas the black box (or regular) version does not. From a research perspective the project had two main threads. The first centered around professional development and classroom implementation issues for simulation-based inquiry learning. For this first research thread we used SimForest-B. We evaluated SimForest-B in clinical and college classroom settings, then ran a professional development institute to train eight secondary school teachers to incorporate the software into their classes. As part of the project we developed curriculum materials and a web site, and we supported the teachers in their classroom implementations. We studied the teacher's and their students' experiences with the software and curriculum.

The second research thread involved SimForest-B and glass box simulations in general. Whereas the first thread focused on learning inquiry skills, the second focuses on learning about quantitative modeling as well as inquiry skills. To build SimForest-G we first built a domain-independent software architecture, SimGlass, for creating glass-box simulations in any domain. SimForest-G was built starting with SimGlass and adding the domain-specific forest visualization interface and the specific model for tree growth. While SimForest-B is a mature software application, SimForest-G is a prototype that has not been used in classrooms yet. However we have articulated some of the theory and pedagogical issues surrounding the use of glass box simulations and learning modeling skills, and believe that this work is a unique contribution to the field of educational software.

Results and contributions of the project, described in detail in this report, are as follows (all tangible products are available from our website at http://ddc.hampshire.edu/simforest/):

- The SimForest-B (black box) software, as used by hundreds of students.
- The SimForest-G (glass box) software prototype, including the SimGlass generic architecture for building "knowledge based" glass box simulations in any domain.
- Curriculum materials for using SimForest in secondary and post-secondary contexts, including: Teachers Guide; Users Guide; suggested activities, lessons and driving questions; concordance table relating important concepts and skills to the sample lessons; templates for student worksheets and lesson planning worksheets.
- An analysis of "best practice" pedagogical strategies for using simulations in inquiry-oriented classrooms, including: methods for measuring inquiry steps and cycles; sample classroom scenarios; an articulation of a number of pedagogical strategies, including novel whole-class strategies for collaborative inquiry activities.
- An evaluation of the professional development and classroom implementation components of the project, including: "Professional Development Guidelines" and lessons learned (applicable to most inquiry-based learning PD workshops and programs); and case studies of the effect of the PD intervention on the participating teachers.
- An evaluation of inquiry skill improvement in the secondary school science classrooms where SimForest was used, including: novel instruments for evaluating inquiry skills and subskills.

During its three years the project had direct impact on:

- 51 college students who used SimForest in class or mock-class situations.
- 195 secondary school students who's teachers used SimForest in the Fall of 2000 (evaluated).
- Over 150 secondary school students who's teachers used SimForest in the Spring of 2001 (not evaluated).
- Over 200 students in middle school classes who's teachers did not use SimForest in the classroom but introduced it to students to use at home; and used inquiry-based methods in their classrooms.
- 12 undergraduate and 1 graduate students who participated as staff in the research project.
- 8 middle school teachers who participated in the project.

The project will have far larger impact as the teachers we worked with continue to use the software and methods that they learned; and as others use the software and curriculum available from our web site. We are currently in discussion with several companies around distributing and/or productizing the software. The SimForest software has been registered or submitted for review to the following on-line educational resources: MERLOT, www.merlot.org; Eisenhower National Clearing House (ENC Online), http://www.enc.org/, GEM: Gateway to Educational Materials, http://www.geminfo.org/, BioQUEST Curriculum Consortium (and BioQUEST Library) http://www.bioquest.org/; Tapped In, http://www.tappedin.org/; EduPlace, http://www.eduplace.net/.

Future work based on the accomplishments of this project include:

- Further development, research, and implementation of glass-box simulations in several domains (grant proposals have been written to NSF and DOE).

- Expanded program of professional development for secondary school teachers in the general area of using simulation-based software (SimForest and other off the shelf and research prototypes) for inquiry-based learning (NSF proposal submitted).
- Planned proposals for further professional development and implementation in post-secondary contexts.
- Productization, distribution, and outreach as mentioned above.
- Further research publications.
- Note that the teachers trained in our summer institute continue to use the software and maintain contact with us.

2 Introduction and Background

2.1 From Classroom to Scientifically Literate Citizen

Even as computers and other technologies increasingly permeate our culture's tools and activities, we find that insufficient numbers of students are drawn to careers in science and technology. This is especially true of students in underrepresented and minority sectors of the US population. There are many probable reasons for this disturbing trend. The issue we focus on is that most teachers are not adequately prepared to mentor students in science and technology subjects and career paths. Even for teachers who are comfortable using technology at home or for administrative purposes, there are far too few who know how to incorporate technology into their curriculum and activities in meaningful ways. Appropriate and meaningful use of technology in the classroom can a) enhance the learning of certain core science concepts; b) increase skills in the use of technology to solve problems; and c) provide students with an understanding of the significant ways (positive and negative) that technology affects the work place and culture. Improvements in these three areas will prepare and motivate more students to enter science and technology jobs and will enable all students, future citizens, to be more sophisticated participants in public and private sphere dialog in an era increasingly dominated by issues related to science and technology.

Much of the focus of contemporary computer-enhanced education is on the use of the world wide web for finding information. It is certainly important for both students and teachers to have skills in finding things on the web and to be able to critique the quality of what they find. However, computers can enhance learning in more ways. In particular, we focus on the use of computer-based learning environments to facilitate inquiry learning. As discussed in many more detail below, computer simulations can provide concept visualizations, skill practice environments, scaffolding, and cognitive tools that enhance the learning of subject matter concepts and skills. Simulations also have the potential to accelerate the learning of inquiry skills and other higher order skills because more "inquiry cycles" can be achieved in a given time period. As discussed in Section 2.4"Challenges to Professional Development", few teachers use simulation-based educational software, in part because they have not had adequate experience, exemplars, or training in the new set of skills and attitudes required. Significant pre-service and/or in-service training is needed to equip teachers to developed open ended activities, evaluate higher order learning, and use flexible methods of organizing the flow of classroom interaction. These issues apply to equally to secondary school and college education, though methods for providing professional development vary in these two spheres.

2.2 Scientific Inquiry Skills

The Presidential Committee of Advisors on Science and Technology's Panel on Education (March 1997) states that citizens in the next century will "require not just a larger set of facts or a larger repertoire of specific skills, but the capacity to readily acquire new knowledge, to solve new problems, and to employ creative thinking in the design of new approaches to existing problems" (p. 5). Modern educational theory stresses the importance of student-active learning and inquiry-based science education to address these educational goals (McNeal & D'Avanzo, 1996; National Research Council, 1996; AAAS, 1993). It has been documented that students often develop a view that science is a method for discovering static facts about the world, and see learning science as learning those facts (Lederman, 1992). In contrast, we wish to foster a view of science as an active process of discovering relationships between observed phenomena; and generating predictions, models, and explanations using these discoveries. Inquiry-based science experiences conducted in relevant, meaningful contexts have been shown to develop higher order thinking skills in students (Roth & Roychoudhury, 1993). Students engaged in constructivist learning (where they actively develop, test, and revise their ideas) developed more sophisticated epistemologies relative to students in a traditional science classroom (Stillings et al. 1999, 2000). They were more likely to understand the relationships between ideas, evidence, theories, and justification in science (Smith et al. 2000).

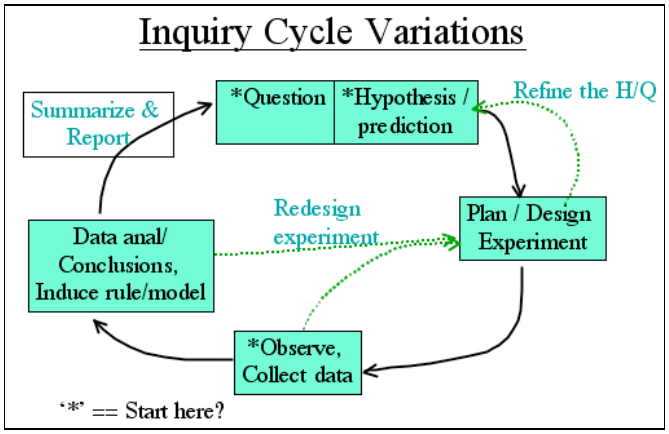

Figure 1 Inquiry Cycle Variations

Figure 1 illustrates a variation of the scientific inquiry model which combines features from several other models. The figure illustrates the four major tasks, plus the "Summarize & Report" (or "communicate") task included in some models. The figure illustrates the following principles: 1) the cyclical nature of inquiry, wherein investigation always leads to new questions, 2) that there are multiple starting points from which to begin inquiry, 3) that the "classical" inquiry cycle is an ideal, with actual inquiry often involving sub-cycles as hypothesis or experiments are revised. In different domains different aspects of the process are highlighted. Inquiry in some domains may involve mainly observation, in others it may involve searching through source texts or web sites, in others it may involve quantitative measurements. The results of an inquiry process may be a case or situation-specific conclusion, or a general rule, model, or principle.

Instructional methods called inquiry, problem-based, case-based, project-based, and discovery-based share many of the same features and address many of the same skills. Supporting students' learning in more authentic, realistic, meaningful, and context-rich situations can enhance motivation, retention, transfer, and depth of learning (Blumfeld et al. 2000; Haury 1993; Krajcik et al. 1998; McNeal & D'Avonzo 1996).[2] Though "inquiry" is most often discussed in terms of science education, the "inquiry subskills" of posing good questions and hypotheses, observing and gathering information, systematically analyzing information, and communicating one's conclusions are important to almost all subject areas, including the humanities (Prince & Kelley 1996). Inquiry involves many sub-skills, each of which must be practiced with appropriate feedback in order to be mastered. Below is a more detailed sample of the subskills involved in doing inquiry (culled from Tabak et al. 1996, Collins & Stevens 1993, White & Fredeiksen 1986, 1995):

- Making **unbiased observations**: separating data/observations from inferences.
- Posing **valid** (clear, confirmable) questions and **hypotheses**.
- Using **clear argumentation** and chains of reasoning--supporting hypotheses and providing sources.
- Shifting appropriately between **brainstorming** or divergent work/thinking and focusing or convergent work/thinking.
- **Systematically exploring** a parameter space and making sure the data collected are representative.
- Organizing data and **looking for patterns**, trends, and categories.
- **Dealing with errors**, noise, and outliers in data.
- Avoiding "**confirmation bias**;" considering counter examples and data.
- Building and understanding **quantitative models** of phenomena.
- Using **metacognitive skills**: reflection, self-monitoring, evaluation, revising, etc.

[2] We acknowledge that such instructional methods can be more time intensive and may require substantial scaffolding to be effective in some situations, and that each teacher must find her balance between "instructivist" and "constructivist/constructionist" methods.

- And, there are many domain-specific skills involved in data analysis, e.g. graphing, statistical analysis, tables.
-

There is some controversy in the literature concerning whether using inquiry methods (and also computer simulations) prioritizes higher order skills at the expense of learning subject-matter content. We have not found this to be the case if inquiry activities are appropriately scaffolded and sequenced. Though the literature contains conflicting studies in this regard and the case has not been "proven" in either direction, we believe that the additional motivation and depth provided by well-run inquiry activities leads to better long term retention and transfer of subject matter facts, concepts, and skills. Current theories in cognitive psychology clearly indicate that more meaning, richness, and authentic use of knowledge leads to more retention and transfer.

2.3 Simulation Environments to Support Inquiry

The use of computer simulations for education, training, and performance support is widespread [Strafford 1997, Gery 1991]. They may be used to emphasize subject matter skills and concepts and to promote general inquiry, problem solving, metacognitive skills. In particular, computer simulations and learning environments provide unique opportunities to practice scientific inquiry skills (see Alloway et al. 1996; Edelson et al. 1999; Gomez et al. 2000; White & Frederiksen 1995; Wilenski & Resnick 1999; Perkins 1986). Straford [1997 pg. 4] notes that "creating and running dynamic models should help clarify one's own mental models and foster deeper understanding of complex systems." Some benefits of these environments include:

- Computer simulations allow students to run experiments and interact with phenomena that may be too impractical or pedagogically ineffective to do in reality.[3] Real phenomena can be too slow, fast, expensive, dangerous, distant, small, large, or messy to observe and analyze.
- They allow learners to "learn by doing" in realistic contexts and can provide visualizations, inspectable models, and powerful analysis tools to enhance learning.
- These environments allow students to manipulate parameters of a system or process and run it in real time, receiving more immediate feedback.
- Simulations can include the randomness, complexity, and emergent phenomena observed in natural contexts, yet parameters can be controlled and varied systematically.
- Students can interact with rich scenarios, carefully observe what is happening, formulate their own questions about phenomena or underlying causes, and systematically answer inquiry questions.
- Errors in measurement and equipment handling are minimized.

2.3.1 Wet vs. Dry Labs

Doing inquiry in "wet" environments can take many days or weeks, and the time and attention lapses between different stages of the inquiry process often impedes clear feedback and continuity of experience for students. Note that it is very important for students to have hands-on experiences that familiarize them with observing and investigating properties of real phenomena such as forests, test tubes, insects, projectiles, and ecosystems. They learn important facts, concepts, and skills by interacting with these phenomena that they would not learn through a computer simulation of the same phenomena. But to the extent that these "wet" investigations are protracted, messy, and error-prone, learning the sub-skills of scientific inquiry is severely impeded (though students do learn the important pragmatic realities of doing real investigations). An inquiry experiment that involves observing plants grow or nails rust can take weeks, and an error made near the beginning of the process can render the entire experiment invalid---a

[3] Many "interactive simulations" are really animations or visualizations of processes, devices, or phenomena, and do not allow users to vary parameters. Seeing visualizations and animations of phenomena, whether on a computer or in an instructional video, can aid understanding for some topics, but for some topics an more interactive experience is required. Our focus will be on simulation software that allows students to do open ended inquiry and experimentation, and thus practice the important skills of asking questions and systematically trying to answer them through trail and error.

frustrating waste of time from the perspective of the student. It is also hard to keep student's attention on the driving questions and issues in the intervening weeks, and they can loose track of why they are doing it. Computer simulations allow students to run many experiments in a relatively short time. Thus students have more opportunities to learn, use, and receive feedback on inquiry subskills.

Our research has indicated that the inquiry cycle (leading from question to data analysis and back to new questions) can be orders of magnitude shorter using computer simulations (Murray et al. in progress). We argue that a student who is able to attempt 15 rounds of the inquiry process with continuous feedback over one month is much more likely to improve important thinking skills than a student who spends the same amount of total time over one month and experiences two or three rounds of inquiry in a wet lab. Still, care should be taken that students have hands-on experiences that allow them to relate what they see on the computer screen to the real world--the danger of loosing the connection between the virtual and the real should not be overlooked.

2.3.2 Types of Simulation-Based Inquiry

Simulations can be used to explore four categories of inquiry questions, as summarized in Table 1. Below we describe these four levels of questions in order of increasing complexity, and discuss how students can black box and glass box simulations can be used for inquiry at each level.

1. Concrete/Situational ("What if?"). Questions that deal with particular observable variables or situations. For example: "what would happen if I started a forest with almost all birches and just two maples?" To answer concrete questions, students simply run the simulation, use the data gathering and analysis tools provided, see what happens, and come to conclusions. In a stochastic simulation like SimForest, the instructor may or many not require students to run multiple runs of the same condition to produce an answer.
2. Relationships ("How?"). Relationship questions focus on the relationship between parameters of the system, and represent more abstract conceptual understating of the domain than the concrete questions. For example: "How does soil quality affect species diversity?" "What is the relationship between soil nitrogen and leaf size?" These types of questions require multiple runs of the simulation using different parameter settings. Depending on the sophistication of the lesson, the instructor may have different requirements for how systematic and complete the student's exploration of the parameter space is. With glass box simulations, the student may be able to determine these relationships by inspecting the model rather than empirically.
3. Explanatory ("Why?"). For example "Why does increased soil quality decrease tree diversity?" These questions delve deeper into the causal relationships and underlying assumptions beneath a phenomena or model. Unlike relationship questions, explanatory questions (under our definition of the term here) can't be determined by observation alone. Students must hypothesize underlying principles and mechanisms, or learn them from the teacher or textbook. (See the meta-model problem in Section 6.1.6.) Using our "knowledge based" approach to glass box models, students can get information about the underlying assumptions and principles behind an equation by inspecting the model.
4. Modeling (abstract "what if?"). . Modeling questions deal with creating new models or critiquing existing models. At this level the learner is considering the system as a whole, rather than looking at one or a small number of variables. It requires an understanding that a model, formula, or simulation is an imperfect and/or approximate representation of the world [Soloway et al. 1997]. Inquiry occurs a meta level in comparison with concrete and relationship type questions. Examples: "What would happen if we replaced the Basal Area equation with a more complicated one that takes tree density into account?" "Can I build a model that causes birches to out-compete maples instead of the other way around as happens in nature?" Only glass-box simulations can be used to do inquiry at the modeling level.

Table 1 Types of Inquiry Questions

	Example	Action to Answer/Test
1. Concrete/Situational ("What if?")	"What would happen if I started a forest with almost all birches and just two maples?"	Run it and observe
2. Relationships ("How?")	"How does soil quality affect species diversity?"	Scientific Inquiry; Graphs
3. Explanatory ("Why?")	"Why does increased soil quality decrease tree diversity?"	Look at equations; Canned explanations in Model Inspector
4. Modeling (abstract "What-if?")	"What would happen if we replaced the Basal Area equation with a more complicated one that takes tree density into account?"	Inquiry in the model space Model Editing

2.4 Challenges to Professional Development and Implementation

Our goal is to have students learn the above mentioned problem solving, inquiry, technology, and subject matter knowledge by training teachers and helping them develop activities and lesson plans for their classes. There are many challenges to creating this type of change in a deep and sustained fashion. Even though it is clear that computer-based learning environments can be very powerful tools for learning a wide variety of topics and many such learning environments have been developed, very few secondary school teachers use simulation-based educational software. There are several likely reasons for this. First, in the past, software that fit the needs of a particular situation was hard to find. This issues is improving rapidly. As web technology improves (with Java, JavaScript, Flash, Shockwave, etc.) interactive activities and learning environments are becoming easily available and inexpensive. The web gives easy access to downloading this software, and more educational resource portal sites are being created to make it easy for teachers to identify quality software and related curriculum materials that meet their needs (e.g. Exploratorium-- www.exploratorium.edu, WISE -- wise.berkely.edu, and NSTA's SciLinks -- www.scilinks.org). As part of the proposed work we will help teachers locate and evaluate quality software.

Second, it takes considerable effort to incorporate inquiry-oriented software into the classroom. Teachers need to learn how to use a software application to a rather high level of proficiency and then has to develop or modify activities, assessment methods, software cheat sheets, and other auxiliary curriculum materials to fit her needs. Also, more open-ended activities require a deeper and broader understanding of the subject matter, because or the broader scope of questions and issues that could arise--adding to preparation time. Teachers are typically very busy (and overworked) and most are unlikely to invest the time required unless the job is made easier and incentives and support are provided--as we propose to do here.

The third issue is the most difficult to change. Using this software in the classroom is a cognitive (and even emotional) challenge for most teachers--much more of a "stretch" than incorporating the Web into class activities as a way to find information. Computer software aside for the moment, there are many challenges in helping teachers adopt inquiry-based pedagogy. Open-ended investigations require a high tolerance for uncertainty, flexible student-centered curriculum models, new models of instructional scaffolding ("guide on the side"), and new techniques for evaluating student work. Windschilt (2002) has shown how important it is for teachers to understand the epistemological underpinnings of new methods that they adopt, and to see these methods modeled for them. Parallel issues exist for the use of technology in the classroom, even without inquiry learning. Thus the goal of introducing technology *and* inquiry is doubly challenging. However there are several factors mitigating the difficulty. First, as alluded to above, using computer-based simulations can make it easier to *teach* as well as learn inquiry skills. Simulation environments are more controllable, predictable, and accessible than most wet lab (laboratory or field) environments. Dealing with experimental data, tracing student activities, and student report generation can be more automated. The novelty factor (and video-game likeness) of computer simulations can make them more stimulating to some students (though gender and other differences must be addressed). The results of several studies indicate that teachers who use technology tend to become more constructivist in their pedagogical orientation over time (see the study by Windschilt & Stahl 2002 who also cites studies by Becker & Ravitz 1999; Means 1994; Mehlinger 1996 to support this hypothesis).

The literature on professional development (PD) and educational reform has substantial agreement on several factors necessary for deep and sustained changes in teacher's practice. Teachers explain that professional development is rife with one-shot workshops attended only to be forgotten, and innovative curriculum materials developed only to sit on the self. It is not that these experiences and materials are of poor quality, but that the time and support systems need to fully integrate them into practice are too often missing. In order to learn and integrate these new skills and resources teachers must receive support as they try to integrate the skills and resources into their existing methods and lessons. They need practice, reflection, and supportive feedback over an extend period. Training must be made relevant to their existing teaching contexts, and new materials must be presented in forms flexible enough to be adapted to these contexts. Unfortunately there is no quick fix or silver bullet to improving teaching. Large attendance one-shot workshops tend to have little impact. Significant resources per teacher must be spent, particularly when the changes being advocated are challenging or unfamiliar to teachers, as in the case of inquiry-based and technology-based education.

In Section 3.3 we summarize our lessons learned regarding professional development that and sustainable classroom implementation of simulation-based software for inquiry learning. Next we describe the SimForest software and curriculum materials.

3 Project Products

In this Section we will describe the primary products of our research project. In the following section we describe research results. Project products include, the SimForest-B (black box) simulation, SimForest-B and SimGlass (glass box simulation, and underlying glass box engine), and a resource web site. In addition, we developed a number of documents to support SimForest-B use in classrooms. These include: a Teachers Guide with teaching guidelines and sample activities and lessons, a Users Guide for the software, and a "How To" guide to help others create professional development workshops about inquiry software. We describe these in the sections below.

3.1 The SimForest Software

SimForest is a simulation-based learning environment in the domain of forest ecology that simulates tree and forest growth, the succession of tree species over time, and the effects of environmental and man made disturbances on forest growth (see Figures 2-3). In the simulation students set environmental parameters such as rainfall, temperature, soil fertility, soil texture, and soil depth; they plant (or load in from a file) a plot of trees from a list of over 30 species; and they "run" the simulation and observer the trees as they grow and the forest evolves. A forest plot's sensitivity to natural and man-made disturbances can be evaluated, and emergent properties such as species succession can be observed.

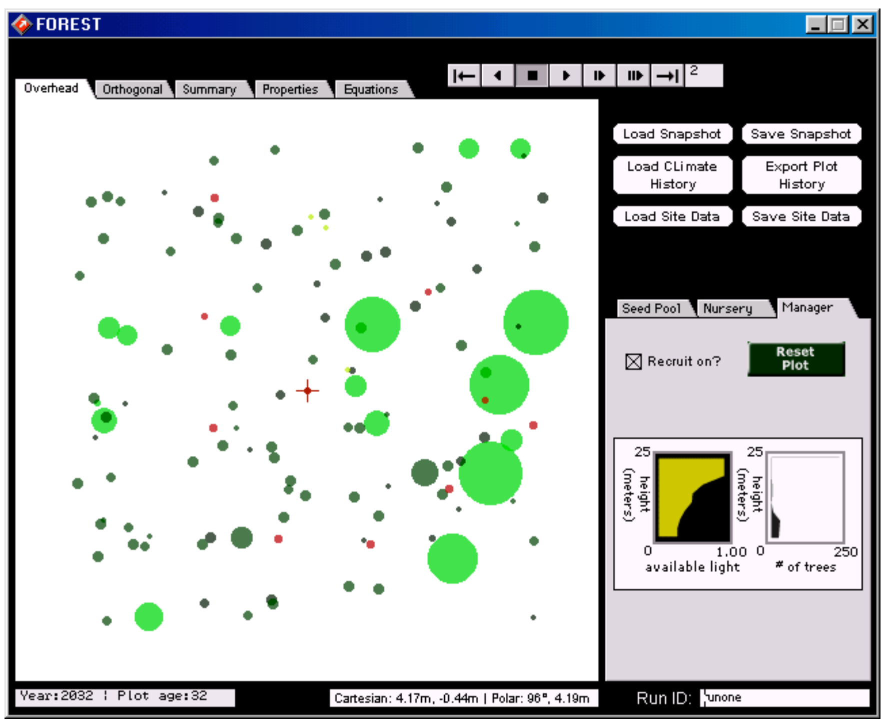

Figure 2 SimForest Overhead View

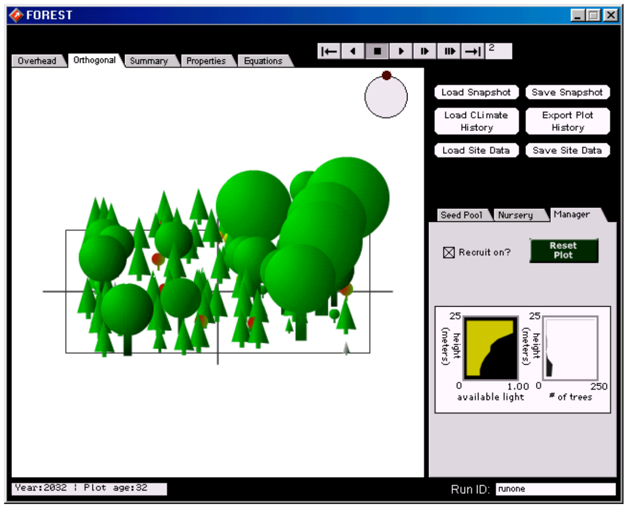

Figure 3 Simforest Orthogonal View

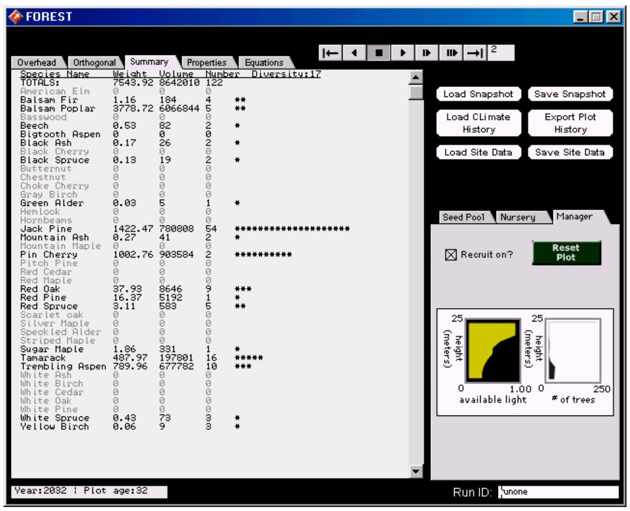

Figure 4 SimForest Summary Window

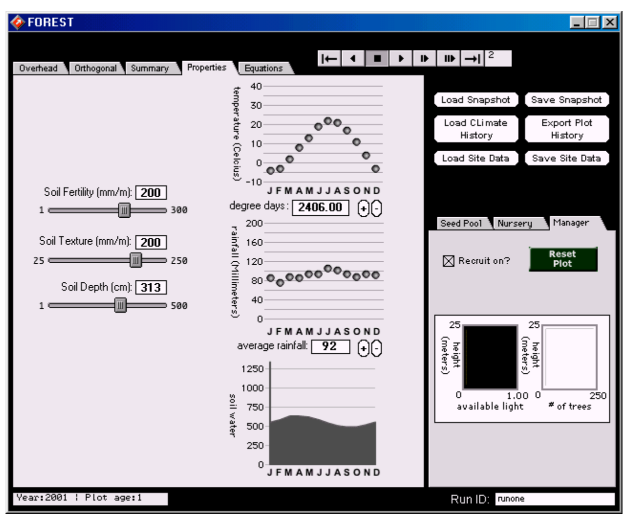

Figure 5 SimForest Properties Window

Simulation details: Three modes are available to visualize the forest growth: overhead view (Figure 2), 3D view (Figure 3), and Summary view (Figure 4). In the overhead and 3D views the user "mouse-over" a tree to see a tool-tip containing information about that tree (species, age, diameter, height, and growth rate). Students can also click on trees to remove them (for example to test the effect of tree pruning strategies) or edit a tree's size or age (which is done in planting a set of trees to create an initial condition for the plot). The Summary view has a dynamically updated tabular list of the species showing total biomass and volume for each, and a histogram showing the number of trees.

The tool pallet, shown to the bottom right of all of the Figures, has three tabs. The Seed Pool tab allows students to toggle which of the defined species are in the seed pool. The Nursery tab allows students to select a species, get some information about it, and plant trees in the plot. The Manager tab shows two visualization tools. One shows the number of trees as a function of tree height. The other shows the average available light in the plot vs. height (for example this tool in Figure 1A shows that full light is available at the top of the canopy, and that the available light becomes closer to the forest floor).

Figure 5 shows the properties tool, where students set the soil fertility, texture, and depth, and the rain fall and temperature profiles. At the bottom of this tool is a visualization tool showing the water available in the water table over the year (available water is determined through non-linear function that takes into account rainfall, evaporation, and snow melt).

Students and teachers can save and load the following files: plots (a set of trees), site parameters (to represent the growth conditions of a particular geographical location); seed pools (a set of tree species, including species-specific growth parameters, characteristic of a particular geographic location), and weather data (a list of monthly temperature and rain fall measurements for one or more years). The simulation, available on our web site, is programmed in Macromedia Director and runs cross-platform. The simulation is model is based on the Gap Phase Model of Botkin (1993), and is described in Appendix 8.1.2. As elaborated on below, the complexity of the model is an advantage from a pedagogical perspective, because it contains a multitude of input and output parameters, and because a variety of processes and emergent properties can be observed. However having a model this complex makes the task of model verification more difficult. The simulation model underwent several rounds of informal model verification, comparing its output to expected output patterns and documented forest conditions. Though we were relatively satisfied with the accuracy of the simulation, it has not been tested in a thorough and systematic way. This, and the fact that the particular model used is a standard, yet relatively old forest growth model, results in occasional behaviors that do not seem to match what is observed in nature. However, since the purpose of the simulation is educational, its accuracy is not as important as in professional modeling software (some of which are mentioned in Appendix 8.1.2).

Unique aspects of SimForest. SimForest is a rich and engaging enough learning environment to be applicable to many grade levels and related subject areas. We have tested in grades 7, 8, 10, and with college freshmen, and we have designed activities that would provide appropriate learning challenges for grades as low as 4th and as high as first year graduate school. Is applicable for High School biology and ecology courses; and College ecology, botany, forestry, forest ecology, and land use planning courses. It can be used in classes that focus on scientific inquiry skills (generic to any domain) and (with the glass box version) is applicable to college course that deal with scientific and ecological modeling.

Many compute-based simulations for educational purposes have been built. SimForest does not significantly extent the state of the art in this area (as does the glass box version described in Section 6), but it does have several features that make it relatively unique among educational software applications. First the domain of forests and trees is familiar to all, and can be readily related to student experiences and authentic curiosity. We commonly observe students posing their own questions and engaging in the types of "sustained inquiry" described in Soloway et al. [1997].

Second, unlike most simulations used in classrooms, it includes **numerous dependent and independent variables**. This provides both opportunities and challenges for classroom implementation. Most educational simulations have few output variables and support practicing the inquiry skills of experiment planning, data collection, and data analysis. Most systems are designed to focus on a small number of concepts, principles, or output results, and the main question being addressed is a given. The multiplicity of input and output parameters in SimForest requires a more complete set of scientific inquiry skills to be applied. For instance, a student interested in using the simulation to investigate the effects of global warming will have to answer the following questions: What parameters need to vary and which should remain constant? What types, sizes, and ages of trees do I start with, how long do I run the simulation, and how many trial runs should I make (perhaps varying different parameters on each run)? What should I observe and measure--should I look at average age, height, weights, frequency of trees, or overall species diversity? Once data is collected there is the question of how it will be analyzed and the results summarized.

Of course, the teacher can create an activity where answers to all of these questions are given, but the simulation allows students to grapple with some of the experimental design complexities of doing experiments in realistic situations. The richness of the simulation allows instructors to **focus on a variety of inquiry skills**, such as making good observations, articulating clear hypotheses, experimental design, data analysis, etc. As we illustrated in the Section on SimForest curriculum, we have found a wide variety of questions and inquiry activities applicable to the software.

A significant value of simulation-based learning is that students can **complete full inquiry cycles** in a fraction of the time it would take to do the "wet" version of an experiment, and thus learn better inquiry skills because they can go through more inquiry cycles. Note that we strongly advocate that students experience phenomena in the real world first if possible before simulating it on a computer, and we incorporate this philosophy into our curriculum materials.

3.1.1 Engagement and motivational affects

SimForest proved to be a rich and engaging learning environment for many students. They maintained active involvement for over an hour and were ready to do more in the next class. Though it must be noted that the instructor's teaching style probably had a positive effect on student enthusiasm and engagement, there were several factors particular to the simulation Because engagement and motivation are important things to keep in mind when designing new simulations, we propose several reasons based on our observations:

- **Familiarity of the domain.** The domain of SimForest, trees and forests, is familiar enough to student that they can start asking meaningful questions right away. Students could readily tap into many potential areas of interest, such as global warming, forest preservation, species diseases, how trees grow, and why a known forest has particular characteristics. The domain of forests may appeal to the aesthetics or romantic sentiments of some studetns.

- **Dramatic attribution and anthropomorphism**. There is evidence of the way that For some students the simulation provided a mock-dramatic flavor, which is engaging or motivational: "Look, we got red oaks" "And gray birch! excellent." -- like the unfolding of a story (see Trial 3C below). Students would identify with particular trees ("that’s a huge maple" or "oh no, my elm died"). They set up little "competition" scenarios in their minds (for example, as one species overcame another, or as they lowered the temperature to see a species trees would dies off). SimForest simulated life-and-death scenarios with completion between species. (These results in this section from College student data were found in the middle school data as well.) Students had anthropomorphic attributions toward the trees, as in “Everything else (the other species) is so happy that they are not giving them [the white pines] enough light.”

- **Competition and gaming**. We noticed a video-game type phenomena. For example in Trail xx the teacher said "try to grow the larges maple." For example:

> Trail 1: S1: [Student has changed the temperature] "hey what is that?! Hemlocks remain!"
> S2: "Oh wow! Where did [those silver maples] come from? …I have a monster silver maple!"

- Richness and complexity. The fact that the simulation is relatively complex leads to a richness in the experience. Interesting and unexpected (even to the expert) emergent phenomena are observed when the simulation is run. It has numerous input and output parameters and many types of investigations are possible. As an illustration of the richness and diversity of potential learning opportunities, we will note that in Trial 3B, at the latter part of the class the three subjects were asked to come up with a question that they would like to investgate. The three had very different responses. One wanted to grow and experiment with "old growth" forests. Another wanted to enter data from a real forest plot and see it the simulation models reality. The third was interested in the model (equations) itself. In another session when asked to come up with their own activity student responses included some who wanted to see what happened if they changed one variable slowly (temperature), while others wanted to take the parameters to extremes and see what happens.

3.2 SimForest Curriculum Materials

We created a Teachers Guide for SimForest that includes activities and instructional methods for using our software in biology and ecology classes for grades 7-12 and college level. The curriculum is designed as a resource for teachers, offered "a-la-carte," as we expect teachers to modify them and sequence them to fit their particular needs. The curriculum is structured to allow emergent student interests and hypotheses to form the basis for sustained inquiry activities. It also connects the simulation activities with outdoor experiences and actual forest growth data. The resource-focused approach proved to be successful for the teachers in our professional development institute. In working with secondary school teachers we observed them modifying our curriculum materials according to: student grade/academic level, previous knowledge, classroom dynamics and learning styles, topical context (e.g. location, season, vacation travel, news headlines).

The Appendix "Tree, Forest, and Ecology Concepts" lists the primary concepts and skills our curriculum materials focuses on. The Appendix "SimForest Teacher’s Guide Lessons List" (compiled by E. Shartar) enumerates the 21 lessons and 9 supplementary activities in the Guide. Note that over half of the activities do not deal with the simulation but deal with hands-on experiences with trees and forests. Appendix "Correspondence Between Lessons and Concepts" shows a resource provided to teachers to map concepts and skills to sample lessons. Here are some sample tasks, activities, and driving questions we have developed for students that involve the simulation (phrased in terms of driving questions):

1. Environmental impact: What if **global warming** did occur? How would the forests in this region change? Would it matter if the change were fat or slow?
2. How would global warming (or a flood, or erosion) effect the **species distribution** and size of local species?
3. **How old** can you grow a tree?
4. **Find the site conditions** to produce: Our woods; an old growth forest; white pines; etc.
5. **How repeatable is this result?**
6. How long do trees live? **Why do they die**? How old can you make a sugar maple?
7. Is a forest static? (its **dynamic**)
8. What isn't the simulation the same each time you run it? (**stochastic** nature)
9. What is the **dominant species** in this run (or plot)?
10. **Diversity** vs mono-cultures: How do **species effect each other**? Try planting a monculture first. Try turning recruitment off.
11. **Succession**. Foresters talk about "succession," an orderly process in which one species replaces another over time. Does this happen in your plot? Which species come in first? Can you test the response of each species to the conditions in the forest during different "stages?"
12. Forest management: If you **clear cut you plot**, what comes in? Does the original forest "**recover**?" How long does it take? Notice what trees come in first.
13. **How stable** are our woods **to disturbance**? If you take a "normal" plot of woods and disturb it to different degrees how long does it take to "get back" to where it started? Does it? How would you know?

14. Given a typical New England forest plot, describe the effects of several **alternative forest management** methods (clear cutting, pruning small trees every year, pruning the largest hardwoods every five years, etc.) on the long term health of the forest.
15. Plant the plot we measured outside last week. Can you guess what **conditions were 100 years ago** that were likely to lead to this type of species distribution?
16. What are the **best conditions for** apple trees?
17. Observe the forest plot in the back of the school and see if you can use the simulation to determine what this land night have **looked like 50 years** ago.
18. What **makes trees grow?** Die?
19. Who can grow the **largest tree**!? Who can grow the most/larges volume of maples?
20. What are the effects of: **draught; pollution;** various arboreal pestilences and diseases…?
21. You have a wood lot and want to heat your cabin. How much cord wood can you remove each year and still have a useful, **sustainable woods**?
22. What percentage of the tall trees can you remove **without allowing early succession** (light requiring) saplings into the plot?
23. You decide you want your trees to grow better so you buy fertilizer. Set up a couple of reasonable climate and soil combinations and see **if adding fertilize helps** growth.
24. Discover that you can't create the plot you see outside without cutting trees down.
25. Effects of **Environmental Changes** , sensitivity to; global warming, pollution: acid rain,
26. Long term **climate change** (hat could grow when there were glaciers?). (And see global warming above.)
27. How does **climate effect**...? (relationship between climate & biotic world)
28. What New England **species would disappear** if global warming increased the temp by 2, 4, 10 degrees?
29. How far (in temp; or how far north) can you go to get rid of sugar maples but still keep hemlocks?
30. Effects of **Natural Disasters**: Hurricane damage, erosion, fire; drought,
31. How much **disturbance** can occur before the forest changes character?
32. You have a known **disease**. How will loosing or reducing the effected species effect the entire forest?
33. Is the **model correct**? (does it correspond to data, observation, or opinion?)
34. Are the species **parameters correct**? (correspond to data, observation, or opinion?)
35. "**Home wood lot**" type questions; if I take out all the maples; what if I had a forest with pines and I planted a red maple in it? (problems with introduces species)…
36. **Forest management**: get an official forest management plan form ("take out x % of Y or B.A. every Z years") and test it.
37. Trees as memory repositories; **forensics**; what happened here?
38. **Interrelatedness** of species: Grow a forest that has red oak and other species. Remove all the red oaks and start growing. They don't come back! Why? (plant one by itself and see if it grows).
39. Create "**phase plots**" that compare the frequency or size of one species vs another. What can you conclude?

In Section 4.3we describe our lessons learned and pedagogical prescriptions for using simulations to teach inquiry.
The Appendix "Sample Lessons from the Teachers Guide" contains two sample lessons. The lessons are structured in four parts: Goals, Questions, Teaching Tips and Background Information, and Additional Activities. Goals describe the purpose of the lesson from a teacher-centric and educational objective perspective. Questions describe the lesson from a student-centric perspective, listing driving questions or curiosities that might lead students to want to engage in the lesson. For example, in the sample lesson "How Does Temperature Affect Forest Composition?" Lesson Goals and objectives include:

- Students will be able to **describe** the effects of temperature on a forest's ***diversity***, as it is demonstrated in SimForest.
- Students will be able to **design experiments** to **predict** possible effects of ***global warming*** on New England forests, using SimForest.
- Students will be able to **compare** and **contrast** different predictions (simulated by SimForest) of the effects of global warming.

And Questions for this Lesson include:

- How does the composition of a forest change with a decrease in temperature? Is there and increase or decrease in diversity?
- How does the composition change with an increase in temperature? Is there an increase or decrease in diversity?
- How might global warming affect local forests?
- Which New England species would be lost if the temperature rose 2 degrees, 4 degrees, 10 degrees?
- Does the speed of the warming matter?
- One concern about global warming is that the temperature will increase more quickly than the seeds of southerly species can migrate north. How could you model this using SimForest.

In each Lesson "Teaching Tips and Background Information" gives suggestions for how to implement the lesson, usually including figures and procedural details. "Additional activities" suggests alternative approaches to teaching the topics of the lesson, and outlines these in less detail than the main lesson was described. As might be evident from our list of lessons and out list of topics there is a "many to many mapping" of topics to lessons. I.E. each lesson addresses a number of topics and most topics are addressed in a number of lessons. Included in the curriculum materials we gave our teachers was a table showing the correspondences between the lessons and topics.

3.3 Professional Development Guidelines and Lessons Learned

The professional development part of our project involved holding a one week institute for 8 secondary school teachers in the summer of 2001, visiting them in their classrooms as they incorporated SimForest Lessons over the next two semesters, and holding 5 quarterly day-long meetings to bring the group together do debrief, teach each other, and plan. In Section 5 we report on our evaluation of the professional development program. One of the tangible products of our research is a document titled "A Guide For Running PD Workshops for Inquiry-based Software Instruction." Appendix 8.3.2 contains a summary of the contents of this document. It gives guidelines for how to design professional development experiences aimed at helping teachers incorporate inquiry-based simulations into their classrooms.

Though five of the eight teachers we worked with in our Summer Institute had very successful experiences integrating SimForest into their classes over the two semesters after the institute, many issues were encountered which could mitigate against successful integration if not addressed. We identified the following issues (these are all elaborated upon in A. Galton's "Professional Development for Inquiry-Based Educational Software"):

- Limitations imposed by state education frameworks
- Limitations imposed by state high stakes testing (MCAS)
- Competing demands from school administration
- Class length too short to delve deeply into an activity
- Too many students in a class
- Large variation in student academic abilities and background knowldge
- Problems with accessibility to computers or computer labs
- Semester timing—getting the sequencing of class topics to coincide with SimForest lessons, interventions, and support services
- Varying student motivation and interest
- Ease of the activities to prepare
- Teacher's comfort and understanding with the subject matter (botany)
- Teacher's comfort and understanding with open indeed inquiry
- Teacher's comfort and understanding with using technology

Through our PD workshop and follow-up support we helped the teachers adapt to these issues. Three of the eight participants of the summer institute did not, in the end, implement the curriculum into their classes. The reasons were clear. In one case a teacher had just transferred to a new school and was overwhelmed with the new set of responsibilities (also, this teacher's lesson preparation style involved a high degree of preparation, organization, and risk-avoidance in comparison to the other teachers). A second teacher taught in a newly renovated school in a town experiencing a budget crisis. The result was that the beautiful new facility did not have a working computer lab and technical services for its first year. The third case was in a way a combination of the first two: this teacher was transferred to a new school unexpectedly *after* taking the summer institute. Because of the resultant aggravation and the fact that the new school had much poorer computer facilities, this teacher could not adopt the software. Though the first of these three teachers dropped out of the program, the other two very much wanted to use the software in their classes, had some of their students play with the simulation at home, and attended the quarterly day long follow up meetings. Seven of the eight teachers intended to continue to use the simulation indefinitely in their classes, as reported in the final follow up meeting.

Section 5 contains results of our evaluation study that indicates that the summer institute and the entire PD experience were very successful from the teacher's perspective. The main factors to which we attribute this success are: 1) Running the institute workshops in a constructivist fashion, where we demonstrated key ideas, let participants engage with the software and concepts in hands-on and collaborative situations; 2) providing ample time for them to become comfortable with the simulation software (by playing with it through open and closed tasks that were similar to what we would do with students), 3) continuously adjusting the workshop to meet the needs of the teachers and supporting them in design lesson plans that directly addressed their need *during* the institute; 4) connecting the project to state science and technology educational frameworks; and 5) providing ample opportunities for teachers to teach us and each other through discussions and reflective activities.

Below we summarize all of our recommendations for professional development, based on our experiences, and principles that we have culled from the literature (see Garet et al. 2001; Blumenfeld et al. 2000; Sandhotlz et al. 1999; Schifter & Fosnot 1993; Simon 2000; Putnam & Borko 2000; Bransford et al. 1999; Howe & Stubbs 1996. Also, see the Appendix "Contents of the How-To Guide For Running a PD Workshop" that lists sections from this document by A. Galton).

- **Interview prospective PD applicants** (in person or by phone) to: 1) allow you to adapt the workshop design based on their available resources, backgrounds, teaching styles and goals; 2) overview the project and explain the expectations required of them; 3) filter out prospective applicants who are not likely to gain from the experience or do not meet its prerequisites..
- **Respect teachers as experts** and professionals. They know more than the workshop leaders about the constraints and opportunities of their classrooms and schools. [4]
- Include **concrete, usable, materials** and ideas along with theory and general prescriptions.
- Ground PD in the **teacher's own subject** areas.
- Provide extra workshop **time to modify and create lesson** plans. They can get feedback from others; and are free of the usual lesson preparation time pressures.
- Provide several **opportunities to practice** new skills, with reflection and feedback. The first time teachers try something new they are likely to have difficulties that can lead to discouragement. Allow them to work out the bugs and gain confidence before they hit the classroom. This is best done first in practice or pilot situations with small numbers of students.
- Encourage **written reflection** on teaching experiences and discussion of these writings.
- Having teachers participate in replaying and **analyzing video taped sessions** of their teaching is a powerful tool for reflection and feedback.
- Materials need to be **flexible** to the needs of diverse classes and student populations. Teachers prefer to be given materials that can be adapted, combined, and composed to fit their needs.
- Articulate, and help teachers articulate, the **objectives of lessons** in terms of facts, concepts, skills, behaviors, and attitudes.

[4] In a form of "action research" (Cobb 2000; Feldman & Minstrell 2000) we also involved teachers in the research aspects of the project by sharing our research goals and methods, and asking them for their suggestions.

- Facilitate **collaborative learning** and discussion among teachers, during and after the workshop. Form communities of learning and buddy systems that allow for peer-support and the ongoing sharing of ideas and resources.
- Relate content to state and local **education standards**.
- Provide methods to **help teachers evaluate** student progress. This is especially important for relatively unfamiliar areas such as inquiry and technology.
- Use and **model appropriate use of technology** to support learning; as in on-line discussion groups, shared repositories for participant ideas and contributions; lists of useful web resources, etc.
- **Practice (model) what you preach**. A PD workshop on inquiry and technology should, in part, illustrate good principles of inquiry learning and technology-enhanced learning. Create environments that support the construction of new knowledge and the creation of knowledge communities, and discuss how the structure of PD experience illustrates important pedagogical principles.
- Extend support and feedback through **classroom visitations** and follow up interviews that investigate teacher's thinking and give feedback from observations.
- Provide adequate **technical support**. Don't underestimate the amount of technical hand holding that may be needed for first use, nor the propensity for Murphy's law to dominate the introduction of new technologies into the classroom. Proactive consideration of seemingly trivial details can prevent entire school periods being wasted.
- Provide tangible **incentives** such as stipends, professional development credits, and materials.
- Secure the **support of** school and district **administration**. This is important to minimize logistical problems, and to advocate for teachers being recognized as leaders and contributors in their schools.

3.4 The SimForest Web Site and Dissemination

Appendix 0 contains a list of materials available on our project web site at http://ddc.hampshire.edu/SimForest/. This website was used regularly by our participants to download software, communicate results, and manage the logistics of our evaluation studies.

The SimForest software has been registered or submitted for review to the following on-line educational resources:

- MERLOT, www.merlot.org

MERLOT is a free and open resource designed primarily for faculty and students of higher education. Links to online learning materials are collected here along with annotations such as peer reviews and assignments.

- Eisenhower National Clearing House (ENC Online), http://www.enc.org/

ENC's mission is to identify effective curriculum resources, create high-quality professional development materials, and disseminate useful information and products to improve K-12 mathematics and science teaching and learning.

- GEM: Gateway to Educational Materials, http://www.geminfo.org/

GEM is a consortium effort to provide "one-stop, any-stop" access to the substantial, but uncataloged, collections of Internet-based educational materials available on various federal, state, university, non-profit, and commercial Internet sites.

- BioQUEST Curriculum Consortium (and BioQUEST Library) http://www.bioquest.org/ -

The BioQUEST Curriculum Consortium actively supports educators interested in the reform of undergraduate biology and engages in the collaborative development of curricula.

- Tapped In, http://www.tappedin.org/

TAPPED IN™ is the online workplace of an international community of education professionals. K-12 teachers and librarians, professional development staff, teacher education faculty and students, and researchers engage in professional development programs and informal collaborative activities with colleagues.

- EduPlace, http://www.eduplace.net/
  This web site is developed for the purpose of providing information and resources for Technology Directors, educational leaders, and teachers interested in technology in education.

3.5 Glass Box Forest Simulator and SimGlass

SimForest-G is a "glass box" version of the forest simulator that was built in Java. It remains a prototype that has not been tested in classroom use yet. In developing SimForest-G we first developed SimGlass, a domain independent architecture and authoring tools for glass box simulations. SimForest-G allows student to inspect and modify the underlying mathematical model. SimForest-G, SimGlass, and the pedagogical principles behind glass box educational simulations are discussed in more detail in Section 6. We have separated this material into its own section because it is not related to our development of curriculum, our professional development model, our evaluation studies.

4 Evaluation of College Classroom and Clinical Sessions

Our evaluation studies are described in two chapters: this chapter describes the results of evaluations of college classroom and clinical trials. The next chapter describes evaluations of a professional development and curriculum intervention in middles schools. The college evolutions severed two purposes: as a formative evaluation of software, curriculum, and teaching strategies; and as a case study of best practice teaching methods.

4.1 Evaluation Methods

In this section we look closely at the teaching behavior of the college professor who facilitated the Hampshire College classroom and clinical SimForest learning sessions. This professor (who we will usually refer to as "the instructor") is considered an expert in inquiry-based science teaching methods, as are most of the natural science professors at Hampshire College. To situate the cases study, and to provide evidence that the sessions we observed provide reasonable data for "best practice" recommendations, we briefly describe the instructor and the college.

Description of the case study instructor. The instructor is a botanist who has substantial familiarity with computers (in past decades he found himself writing Fortran code as part of his botany research). He had not used simulation-based software very extensively in his teaching in the past (though spreadsheets and web searches are common). However, he was a major part of the SimForest design team, thus he knew the SimForest software intimately and had been considering how it could be used in instruction for some time. In a later Section we discuss the extend to which the observed teaching strategies of this instructor could reasonably be transferred to other instructors.

Description of the case study institution. An inquiry-based educational philosophy is deeply embedded into Hampshire College's academic structure and course offerings, as well as in the faculty's teaching methods [Prince & Kelley 1996]. Since its inception the College has affirmed that meaningful education engages learners in increasingly sophisticated, student-driven, and realistic problem solving. Science education in particular uses an innovative and nationally acclaimed student-centered research-based approach. The College has been particularly successful at encouraging students who had not come to college to become scientists and to go on in careers in science and science teaching.[5] The practice of, reflection on, research of, and wider dissemination of innovative pedagogy are deeply rooted in the College's academic culture, around which the College has hosted many grant funded research projects.

Goals of the case study. A primary goal of this phase of our research was to document a variety of successful inquiry-based methods for using simulations in the classroom. In the fashion of "action research" (Cobb 2000; Feldman & Minstrell 2000) the instructor was both a subject of study and a participant in developing the study. In planning each learning session (classroom and clinical) he varied the methods that he prepared to use, often adapting the lesson plan based on what was learned in previous sessions, thus allowing us to observe a variety of activities and "driving questions" (Soloway et al. 1997). However, though some pre-planning was involved, much of each session involved responding and adapting dynamically to the needs of the students as they engaged in open ended tasks. The instructor did this using his particular teaching style. Thus our research involved two overlapping methods of investigating inquiry-based pedagogy: 1) we characterized how the intuitions of an expert in inquiry style teaching manifested in the context of SimForest classroom; and 2) we observed a trail-and-error approach to exploring the effectiveness of variations of inquiry-style activities. Our results, a set of observations and prescriptions for

[5] While only 7% enter the college to major in science, 15-20% actually fulfill their degree requirements in the sciences, a remarkable reversal of national trends Our science program has been recognized as innovative and supported by major grants from foundations such as the Howard Hughes Medical Institute ($3 million) and the NSF.

methods and activates for simulation-based inquiry learning, represent a merging of what we learned from both sources: the case study of an expert instructor, and a trail and error method (it is not possible to separate these two sources of information in the observed classroom behavior).

Overview of case study sessions. Over three years we completed five rounds of formative evaluation of the SimForest-B software with college students. Three of the sessions were in a Hampshire College 100-level course titled "The Ecology of Old Growth Forests" which was taught by Larry Winship every Spring, and was attended by a mix of college freshmen and sophomores. The other two the sessions were in clinical settings (done in the Fall of two years) in which we observed five to seven students using the software (these subjects were paid for participating). The clinical sessions were set up like classes, sometimes starting with Winship giving an introduction to important botany concepts, and continuing in a way similar to his classroom teaching style (except with fewer students).

In all sessions, classroom and clinical, students worked in pairs or threes (except for an occasional classroom student who wanted to work on his or her own). All trails involved a minimum of "lecture style" and a series of open ended tasks to be done using the simulation, punctuated with periods of bringing the entire class together to discuss what they had discovered. During the exploratory tasks the instructor walked around the class to answer questions and give hints when students were stuck or at a "teachable moment." Occasionally the instructor interrupted the independent exploratory work to share with the entire class some information that was inspired by an individual's question. After each session or series of sessions students were asked to give general feedback on their experiences in a focus-group fashion. In several of the sessions one or two video cameras were set up, each observing one pair of students and the computer screen. Specifically, the trials were as follows:

- Trial 1: the software was used during two sessions of a college class, with 7 students working in groups of 2 or 3. Data included observational notes, transcribed video tapes, and student feedback questionnaires.
- Trial 2: Six subjects used the software in pairs for two 2-hour clinical sessions. Data included observational notes, and transcribed video taped sessions.
- Trail 3: the software was used in a college class, where 16 students in small groups used the software for three class sessions. Data included observational notes and transcribed video tapes.
- Trial 4: Seven subjects used the software (in two separate groups) for three 2-hour clinical sessions. Data included detailed session notes.
- Trail 5: the software was used during one 1.5 hour session of a college class with 15 students working in pairs. Data included detailed session notes.

In total of 51 college students used the software in these trials over a total of 14 instructional sessions which lasted one to two hours each. As these were formative evaluations, earlier sessions identified software bugs and needed improvements that resulted in improved performance, usability, and capabilities over the course of the five trials, as the software was continuously improved.

Appendix 8.2 contains the questionnaire used in Trail 1. Appendix 8.2.1contains the rubrics used to score the video tapes. Most of the tapes were scored by one of three scorers that were used over the three years of the project. As the experimental method used is similar to case study and ethnographic methods for characterizing situated behavior, multiple scorers were not required. Appendix 8.2.2contains a summary of the activity flow of most of the sessions.

4.2 Results of College Trials

4.2.1 Student Questionnaire Results

Students involved in the Trail 1 class were given a post-questionnaire that consisted of 12 Likert-scale questions and 7 fill-in questions (see Appendix 8.2) to discover how they valued the experience, the simulation software, and biology courses in general. The questionnaire yielded the following overall results (the sample size is too small for statistical analysis):

- Students who "enjoyed natural science" found the software easy and enjoyable to use, and said that they preferred to use simulation technology to do science experiments, while student who did not "enjoy natural science" tented to rate the software lower and were more confused about the task.
- There was an indication that students who did not feel that they had enough background knowledge to solve the task found the simulation more difficult to use and the tasks more difficult to complete. These findings lead us to design a set of more scaffolded tasks.

Throughout our study we found that students were motivated and engaged. In Section 3.1.1 provide evidence of this in the College classroom context, and in Section 5.2.1we provide evidence of this in the secondary school context. Do to the large number of uncontrolled variables, we did not attempt to measure learning gains. However, we did measure inquiry cycle activity, as discussed next.

4.2.2 Tracking the Inquiry Cycle

We used two methods to track stages in the inquiry cycle as students engaged in SimForest activities, one global, and one local. At the local level we tracked the individual steps in the inquiry cycle (see Section 2.2 for a discussion of inquiry cycle components). In two classes (from Trail 1) where the activity was very open ended, feedback was predominantly individualized, and there was little full-class discussion, we analyzed video tapes of student sessions to code for inquiry cycles. At a global level a second method was used for sessions that had more teacher scaffolding and full-class discussions. For these cases we analyzed observer notes taken during the classes and noted how the entire class self-organized into cycles of divergent individualized work and convergent full-class discussions.

Two videotaped sessions from Trail 1 were analyzed to produce the data in Table 2 (the same research assistant coded both sessions). The approximately one-hour sessions were divided into naturally occurring "episodes" of varying length, averaging about 2 minutes per episode. The two sessions involved pairs of students using the simulation who were given open ended assignments to investigate an issue of their choice.[6] The instructor was circulating through the room to offer help during the sessions. Examination of the data tables leads to the following conclusions:

- One can clearly see the occurrence of inquiry "cycles" in the data. The cycles do not always include all of the normal steps of inquiry, but there is a clear pattern.
- Most of the cycles do not involve posing a new hypothesis, but rather students start a new experiment after making a verbal observation or conclusion, or after realizing they need to redesign the experiment to obtain the results they desire.
- The average inquiry cycle is approximately 10 minutes in length.

[6] The table does not show that in session B in the 8-10 episode rage the students rapidly tried several values for the temperature parameter and ran the simulation for few seconds.

Table 2

Episode-->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SESSION A:																														
Ask question		x																												
Refine question		x																												
Make hypothesis			x																											
Plan experiment				x																										
Set-up experiment					x					x				x				x												
Run Simluation						x					x				x				x			x								
Record data																														
Verbal observations							x					x				x				x			x							
Refine Method									x				x				x													
Data analysisi	x							x													x			x						
Summarize																									x					
SESSION B:																														
Ask question	x															x														
Refine question																														
Make hypothesis										x							x													
Plan experiment																		x												
Set-up experiment																			x											
Run Simluation		x			x			x				x								x			x				x			
Record data																														
Verbal Observations			x			x			x				x								x			x				x		
Refine Method				x			x				x											x				x				
Data analysisi														x											x				x	
Summarize															x															x

The following is a condensed transcript from part of Session 1B:

The students "planted" trees in the simulation to replicate the forest plot that they surveyed outside. They noticed that trees were dying at a rapid rate. The instructor suggested that they try to figure out why this was. An hypothesis was made that the temperature of the plot was not set correctly. To test this, the students changed the average yearly temperature to 32 degrees (Fahrenheit), and observed that all of trees died (even more rapidly than before). They then tried setting the average temperature at 80 degrees and observed that the trees again all died. They tested a few intermediate temperatures, finally arriving at 70 degrees, where only a few hemlocks were seen to grow. Over time they noticed that silver maples grew in and outnumbered the hemlocks. Eventually most of the silver maples died then hemlocks came back in to dominate the plot. From this experience the students posed a new question: "what would happen if only silver maples were planted?" They continued on to explore this question.

The students in Session 1B were not exploring the space of parameters very systematically, and they were not basing their questions and inferences on correct knowledge of botany (this was still early in the semester). However, the session shows clearly how a the richness of the simulation leads naturally to cycles of student-motivated questions and experiments.

Transcripts of video taped sessions from Trail 2 Session B and Trail 3 Sessions B and C were also analyzed for inquiry cycles. Because the classes had more full-class participation, the scoring method was different but compatible with the one used in Trail 1 (observations were grouped into 5 minute episodes, and the inquiry steps observed were categorized as question/predict/hypothesize, plan, analyze/model, or conclude/communicate). The results showed clear cycles, as was found above. However, in these three sessions the length of the cycles varied from 10 to 35 minutes. This was in part due to the different tasks and greater variety of teacher interruptions in these sessions. Also, we concluded that the more flexible episode delineation method used for Trail 1 was more sensitive to tracking shorter inquiry cycles and sub-cycles.

In summary, we can note that the 10 to 35 minute length of the typical inquiry cycle is quite manageable in classroom settings, and always allowed for multiple cycles within one class. Though there are many aspects of comparable "wet labs" that are not included in simulation-based labs (as mentioned in Section

2.3.1) we conclude that simulation-based labs allow more inquiry cycles and thus more practice and more immediate feedback on inquiry processes, and have the potential of more efficient inquiry skill learning.

The second method of measuring inquiry cycles, at less detailed level of analysis, was to analyze the flow of class activity. Specifically, we noted how many times the class cycled between small-group inquiry activities on the computer and whole class discussions. Appendix 8.2.2 contains a summary of several sessions at this level of granularity. We have clear data on these inquiry cycles from only four of the sessions (for other sessions we did not have clean observational notes, or the session was run entirely in individualized mode). For sessions 2B, 3C, 4A1, and 4B1, the number of times the class broke into simulation-based sessions was 4, 4, 5, and 4, respectively. Since the sessions lasted 1 to 1.5 hours, we can conclude that on the average the instructor cycled between whole class and independent work about every 20 minutes. Note that the strictly simulation-based inquiry and inquiry steps mentioned in the first method above can occur within these larger grain sized episodes. I.E. once the students began their independent work they could have gone through several inquiry cycles before the class was brought together again.

In summary, we note that the instructor tended to cycle between independent work and discussion about every 20 minutes, and that (based on the previous analysis) students probably were able to engage in one to 3 inquiry cycles during this time. This is a measure of how "far" into independent work the instructor let the students go before bringing everyone together to synthesize what was discovered and give those who might be stuck the opportunity to ask questions in a full class context.

4.2.3 Session Descriptions

Next we will describe five SimForest sessions. After each we will briefly summarize some important pedagogical points. In succeeding sections we will give an overall pedagogical analysis and prescription based on all of the sessions.

4.2.3.1 Trial 2B

In this trial six subjects used the software in pairs for a 2-hour clinical session. The instructor started out with an introduction to relevant botany principles and an explanation of some of the characteristics of the SimForest growth model (probably because the students were volunteer subjects not in a botany class). He described the light factor and how the shading leaf weight of trees at various heights effects trees. He discussed a major factor in tree death, that as trees get older the ratio of leaf weight to tree mass becomes smaller. He described the "gap phase model" used in our simulation, which averages the effects of each tree over the entire 20 meter plot. He sketched graphs on a blackboard that illustrated a typical distribution of tree ages and diameters in a plot, to discuss the tree diversity and randomness of tree attributes. He asked the class to brainstorm about what factors effect tree growth. Cumulatively they correctly mentioned light, soil, exposure to elements, and rain. He briefly described tree species succession.

The instructor then lead the class through an experimental activity using the simulation, which also served as an introduction to the software. First he asked them to use the site properties tool to set the rain and temperature to reflect local conditions. To help with this gave a handout that showed average weather conditions for the Amherst region. He asked the students to grow a plot (run the simulation) starting from a clear-cut plot. He asked "are all of the plots the same? Why not?" This lead them to discover the stochastic nature of the simulation. He asked the class if any of them saw white pines in their plots, which were common in our locale. Few were found. The he said "see if you can get white pines to grow by paying with the site properties." As students engaged in this open-ended experiment, The instructor walked around the class and was observed giving the following advice:

- "Take baby steps in your investigation."
- "You may want to take notes."
- "That looks a little rich for our forest here. try less fertile soil."
- "Look for whit pines and scarlet oaks too."

- "Remember, you have to let it run to see tree succession before you change things. white pines may not grow right away."
- "Clear the plot and start over when you change conditions."
- [when asked a question] "Try to find that out yourself."

After about 15 minutes The instructor brought the group together again. He recorded on the blackboard what they found as the best conditions for white pine, noting "we have rough agreement here." Next he suggested an exercise with the goal of teaching students about the stochastic nature of the simulation and the implications of this for data analysis. "Now everyone start with the same conditions: soil type 70, soil fertility 130, soild depth 350, average temperature 60, and average rainfall 78." "Grow the plot several times for the same length of time and compare." The ensuing class discussion illustrated that the students understood the point.

Next he organized a collaborative distribution of a problem solving "search space" to more precisely find the optimal conditions for white pine growth. "Lets get organized and do some experiments" he said. He asked group 1 to vary the temperature, group 2 to vary the rainfall, and group 3 to vary the soil fertility, leaving all other variable constant as in the previous experiment. "You will be simulating global warming, draught, and composting" he said. "We will have 10 minutes for these explorations, and then we'll talk about what you found. Take notes!" "Lets grow each forest for 100 years. Take a census at 50 and 100 years." Several students wanted to know whether the soil fertility changes as trees die and decompose. The instructor explained that the model did not include this level of detail, and assumed a constant soil fertility, which was an OK first approximation. Students worked in three groups as suggested and found the optimal ranges. A class discussion and summary followed.

Analysis:

- Students who were not in a botany class were given 20 minutes of introduction to concepts before the session. This type of introduction is probably necessary and sufficient.
- Note the balance between what is given ("taught") to the students and what is left for discovery. In this session all general botany principles are told to students. The inquiry is around discovering things related to specific species or site conditions.
- There were several instances where the instructor reframed questions and refocusing students attention toward for more productive learning.
- The instructor scaffold the session by progressing from open ended exploration to more systematic ones.
- The session had the characteristic pattern of cycling between convergent (whole class) and divergent (simulation-based) episodes.
- The instructor seemed to be using a strategy of accumulating the collective knowledge of the participants.
- The instructor organized the students into a collaborative exploration of the problem space.

4.2.3.2 Trail 3C

In a class of 16 students, the instructor started with a discussion about what they observed on a field trip into the woods. Students had visited two dissimilar locations (at the Dunbar Brook and Amethyst Brook conservation areas) and recorded what species they observed at each one. Photos of trees were projected on a large screen. The instructor initiates a discussion of how trees die (as they get older, the leaf to volume ratio gets smaller and the trees become weaker and more susceptible to disease and weather conditions). The class is instructed to start up the simulation and play with site properties until they observe the species list that they saw during their field trips (picking one of two field locations). Students initially express excitement:

S: "Look, we got red oaks."
I: "And gray birch! excellent!" "You also got hemlock, which means your climate is a bit colder than here."

After 10 minutes the instructor decides that this task is too difficult, brings the class together for discussion, and assigns a simpler task: "how long does it take to generate a white pine forest from an open field?" After the students experiment with this for 10 minutes, he brings them back together and asks the following questions, which were interspersed with student and teacher dialog: "How did you get the white pines?" "How big did they get before they died?" "How old did they get?" "How does this compare to what we saw outside?" "Lets try yellow birches. Grow the biggest one you can." After about 10 minutes the instructor brought the class together again.

From observing the students interact with the simulation the instructor could see that the model (or the species parameters for yellow birch) did not behave as expected. However, he was still able to engage the class in a discussion around important concepts. Finally he assigned this task: "Clear the forest, turn recruiting off, and plant just birch or maple or whatever. Grow it for 100 year. See what happens. Then turn recruiting on and see what happens." (Note: turning recruiting off stops new trees from germinating.) Using this activity the instructor was later able to focus the discussion on the interaction of species.

Analysis:

- The simulation activity was grounded in observations from a field trip, and simulation results were compared with field trip results.
- There is evidence of the simulation providing a mock-dramatic flavor for some students, which is engaging or motivational: "Look, we got red oaks"… "And gray birch! excellent."
- In a related way the simulation can have a "gaming" nature which can provide motivation: "Lets try yellow birches. Grow the biggest one you can."
- There were two instances of the instructor's dynamic re-planning based on unexpected problems. In the first, the task was to difficult and a simpler task is assigned, and in the second a bug in the simulation model lead the instructor to break the task into diagnostic sub-parts.
- An activity was repeated: once with white pine and the second time with then yellow birch.

There is evidence of the opportunistic conveyance of subject matter information during a "teachable moment": "You also got hemlock, which means your climate is a bit colder than here."

4.2.3.3 Trail 4A1

There were two pairs of students for this clinical session. The class began with a brief introduction to our research project. This was followed by a 10 minute discussion and Socratic dialog about trees in which the instructor asked students questions about how trees get their energy (from the sun and photosynthesis), what they need in order to grow (light, carbon dioxide, water, a range of temperature, and soil), and how different trees might interact when they grow in the same plot (by shading each other).

To introduce the students to the software the instructor gave them a relatively specific task: Grow a forest and watch what happens in it over the course of 100 years. The instructor began by showing them how to use the overhead and orthogonal views and asking them to make qualitative observations of the forest through time (e.g. “What do you see happening as the forest goes from 0 to 100 years old?”) At the beginning of the developing plot a number of small trees came in, but as time went on and these trees grew, many of them died out. New trees came in and eventually the plot consisted of a smaller number of large trees. By scrolling over the visual displays students could determine the species of each tree on the plot, but it was time consuming and difficult for them to do this for every tree. This provided the perfect opportunity to show students the summary window, which listed (in this version of the software) the number of stems per species. When the instructor asked the students to compare their species lists with each other they discovered that though the species compositions of their plots were similar, they were not identical. the instructor explained that this was because there was randomness built into the model.

Next, the instructor introduced the students to the site properties window where they could change the climate and soil characteristics. He did not give students specific instructions, such as “Now everyone click on the left button,” but he did guide them through how to use many of the features. After this the instructor gave students time to play around with the site properties without any specific assignment. After a few minutes of this, the instructor suggested that they try to grow a Northern Hardwood forest composed of sugar maple, beech and yellow birch. It was somewhat difficult for students to figure out how to do this by themselves without knowing anything about the requirements and growing conditions of these species, so The instructor gave them hints about how they might change the soil and climate conditions to favor these species.

During this investigation one student noticed that jack pine (a species that is not native to Massachusetts), which had dominated the site at the beginning of the run time, eventually disappeared completely. After the student had pointed this out, The instructor asked, “Why do you think that happened?” and another student answered, “light.” The instructor proposed that students test this hypothesis by simulating disturbance, or “cutting down” trees to create gaps in the canopy, but one of the students thought that the jack pines might come back eventually if we waited long enough. So, one pair of students tested the first hypothesis by removing trees from the plot and the other tested the second hypothesis by letting the forest grow without making any changes.

The first team succeeded in getting jack pines to grow, after cutting down most of the large trees. The second team did not grow any jack pines, but their experiment was just as useful as the other because it allowed students to see both outcomes. The first team’s results demonstrated the effects of disturbance, while the second team’s results served as a control and also introduced the concept of a climax forest that may exist in the absence of disturbance. Both outcomes were also informative about the conditions that favor (and do not favor) jack pines.

Analysis:

- In this session the simulation's Summary view was introduced to the students after they demonstrated a need for the type of information that the Summary view easily provides.
- In learning about modifying Site Properties, the instructor had the students "play around" with it first, then he assigned a specific task: to grow a Northern Hardwood forest.
- Later we will discuss the open-endedness of activities. We can note here that there are two aspects of how specific a task is: what to do and how to do it. The instruction to "Grow a forest and watch what happens in it over the course of 100 years" was specific about what to do but not how or what to measure. The instruction to "try to grow a Northern Hardwood forest composed of sugar maple, beech and yellow birch" is specific on what to observe but not about what do to experimentally. We found that clarity on the "how to observe" aspect of task instructions was especially important in working with the secondary school classes.
- The instructor asked students to compare their findings with each other. In addition to allowing students to share their skills and experimental results, this seems to create a motivating social context for the exploration.
- The instructor dynamically create an activity based on a hypothesis generated by a student. The two groups each tested an alternative hypothesis and in the end one of them was confirmed.

4.2.3.4 Trail 4A2

In this session there were only 3 students. Two worked together and the third worked alone. The class began with a discussion of trees growth. The instructor asked students questions about how trees get their energy (from the sun and photosynthesis), what they need in order to grow (light, carbon dioxide, water, a range of temperature, and soil), and how different trees might interact when they grow in the same plot (by shading each other).

To introduce the students to the simulation the instructor simply showed them how to open the software and told them to “See what you can discover.” His aim in doing this was to allow students to engage in an open-ended discovery of how to use the software. However some students had difficulty figuring out how to use the software on their own, which left them unable to use it to explore interesting questions. The instructor ended up leading the students through the features of the software one at a time.

After students had been introduced to the basic tools provided in the software, including the different views and the summary and properties window, one student commented that jack pine, which was the first species to colonize the plot in large numbers, does not grow around here (Amherst, MA). She wondered what the forest would look like without that type of tree. The instructor showed the students how to take jack pine out of seed pool, and they discovered that without jack pine, pin cherry, which had been the second most dominant species with jack pine, became the dominant pioneer species.

Once this investigation was completed, The instructor suggested that the students pick one of the species in the seed pool and see how old and large they could get it to grow. In order to do this students tried a number of techniques, which included planting their chosen tree (often this resulted in a seedling that died within the first year), cutting down all the other tree species, limiting the seed pool, and changing the site properties. Students conducted their investigations in a semi-systematic manner. That is, they generally changed one site factor at a time, though sometimes two, and their increments of change were not uniform (i.e. they might change the rainfall by one inch the first time and 3 the next.) They did not record any of their methods, hypotheses or results, and their technique was basically trial and error.

Analysis:

- The completely open ended (just play with it) introduction to the simulation was not as efficient as the introduction in 4A1, in which a more specific task was given as a context for learning how to use the simulation.
- We find another activity created dynamically based on a student question
- Regarding the specificity of the task instructions, we again find an example where what to do was not specified what to measure is specified: "pick a species and see how old and large you can get the trees to grow." Students were left to themselves to systematically or unsystematically vary plot conditions in their experiment.

4.2.3.5 Trail 5

The 15 students in the class had already spent 3 weeks engaged in the study of forest ecology. Their previous discussions included such topics as photosynthesis, abscission (the process by which trees lose their leaves), what trees need in order grow, and the way that humans have affected the woods of this region. They had also read about the history of New England forests and gone on a number of forest exploration and plot surveying field trips. An advanced student who had previously taken the instructor's course and was familiar with the simulation was a teaching assisting. The following is a summary transcript of the first classroom lesson with SimForest.

The students worked in pairs on computers (with one trio). The instructor asked the students to launch the application and immediately play with running the simulation. They were asked to look at overhead view and 3D view. "What do you notice?" "Now look the Summary view." "Do you see species you recognize for the field trip?" The list of species that students generated from their field trip included sugar maple, red maple, hemlock, white pine, red pine, white birch, yellow birch, black birch, white oak, red oak, and hickory. The instructor suggested that the students remove all species except for these 12 from the seed pool.

"Now run the simulation with the limited seed pool for 50 years and then compare your results another pair's run." “Why aren’t all of your plots the same?” A short discussion of the stochastic nature of the simulation ensued.

Several students noted that the results did not resemble what was seen in the field. The instructor made suggestions about how the site properties might be changed so that the simulation would more closely resemble what was observed outdoors. Among the changes was an increase in average temperature. He then asked them to run again for 50 years and compare with each other. Below is some of the conversation (with S indicating "student").

> S1: “There are more tree species this time.”
> I: “And what is another way of saying that there was an increase in the number of trees?”
> S2: “There was an increase in diversity.”

> I: “So with an increase in temperature we saw an increase in diversity.” “Does this go along with your intuition? Where on Earth do we see the most diversity?”
> S3: “The tropics.”
> I: “And the least?”
> S3: “Antarctica.”

None of the above information had been previously discussed in class.

In order to gain a better idea of which conditions favored the species of the surveyed plot, the instructor told each pair to choose one of the species from the surveyed plot and see how old and large they could get it to grow.

As the class continued with their investigations The instructor would occasionally address the entire class with tangential information. For instance, one student's private question lead The instructor to explain to the entire class that, although most people think that leaves fall off because of wind or rain, the loss of leaves is actually an active process, which he went on to describe, including an explanation of why some trees drop their leaves later in the season than others.

In the final activity of the class the instructor gave more freedom, asking students to pose any inquiry question based on their curiosity. He told them that they could grow the plot for longer than 50 years and decide for themselves how to conduct their experiment. As an example, one group tried to get more red oak to grow on their plot. As before, The instructor and the advanced student moved through the working groups answering questions There was not time in the class period for the groups to come back together to share what they found.

Analysis:

- Again we find grounding inquiry on previous shared field experience.
- There is some evidence for the importance of background knowledge in creating engagement. The students, three weeks into the class on forest ecology, tended to ask deeper questions and become more engaged in discussion and experimentation than in similar classes with less background knowledge.
- The completely open ended introduction to the simulation ("run it and just play; what do you see?") seemed to work this time. This is also likely due to student's increased background knowledge. They were automatically interested in what was happening, it made sense to them and they and did not wonder "what am I supposed to be looking for?"
- We can see an evolutionary flow of activities, in which one activity naturally leads to questions that motivate the next activity. In some cases a student question leads to the next activity. In this was we can see the instructor trying to engineer teachable moments into the sessions.
- We can see scaffolding of simulation tasks, and gradual fading as activities become more and more open-ended.
- We can note that in this class, and in many others, students did not engage in completely systematic explorations of the parameter space. This was only seen when the instructor scaffolded it.

We again see an instance of the instructor orchestrating a collaborative search of a parameter space; this time by having each group choose a different species to test.

4.3 Pedagogical Strategies

In the following sections we generalize our observations and analysis from all 14 SimForest sessions to produce instructional strategies and pedagogical principles for leading simulation-based inquiry activities in classrooms. Though these recommendations are based on the case study of a college botany professor described above, be believe that most of our findings are applicable across grade levels and science subjects. In our work with secondary school teachers we observed many of these strategies (though not usually as many or done as expertly as in the college sessions) and in our Summer professional development institute we endeavored to model and teach many of these strategies. The majority of the strategies identified apply to scientific inquiry activities with or without computer simulations.

4.3.1 Categories of Instructional Strategies

We have organized our findings based on the following distinctions that we found useful in analyzing the data. These distinctions are important because the literature often refers to "student directed," "student centered," or "decentralized" classrooms, yet we found it necessary to distinguish among several different modes or facets of student-directedness. Students can directly suggest what to do, or a teacher's decisions can be oriented around students' moment to moment pedagogical needs (whether or not the students are aware of these needs). In addition, we found that student-centeredness can come both from the degree of *control* focused on students, and to the degree of *information* coming from students vs. the instructor.

The "flow of control" in a classroom, i.e. the decision about what to "do next," can be based on global pre-planning or on dynamic opportunistic planning. The activity chosen tends to fall into two broad categories: full class discussion/lecture, or individual student/group inquiry. The impetus for deciding what to do next can come entirely from the teacher, or can be in direct response to a student. If it is in response to a student it can be to follow a student suggestion, or in response to a student question or issue.

The above was about the flow of *control* in the classroom. There is a related distinction about the flow of *information*. Who is providing the information: the teacher or the students? A teacher who uses a Socratic teaching style is in full control of the flow of the class, but organizes the flow of information to come primarily from the students. In some classes the teacher poses as the "expert," while in others the students are empowered to be experts in some small domain. They are encouraged to create and negotiate their knowledge individually and collectively.

In the sections below we deal with general issues of inquiry-based instruction before dealing with strategies specific to computer simulations. Within the general inquiry strategies we firsts discuss local scaffolding and then global scaffolding. At the local level are strategies (or tactics) that respond dynamically to classroom situations. Included are strategies for hints, leading questions, and teachable moments. At the global level are strategies for planning an entire class, usually done before hand (but the entire class structure can also be created dynamically, so the two categories are not completely distinct).

4.3.2 Local and Dynamic Strategies

First we will discuss strategies *within* and activity, and in the next subsection we will discuss how activities are sequenced. Local/dynamic strategies involved the instructor responding to student questions, answers, and needs for help. In the case study we saw numerous instances of the following phenomena:

- **Leading questions and Socratic dialog**, i.e. asking questions rather than giving information. This is usually an attempt to show the student they already know or could figure out the answer; or to give just enough info to allow them to answer their question.
- **Emergent curriculum and question/need-based dialog**. All other things being equal, it is better if the flow of the class emerges from student questions. However, we found that, especially in classes where students had little background information, the instructor could not rely on students posing relevant and clear questions. Though we did observe many spontaneous questions that lead directly to simulation-based inquiry, such as "what will happen if we take out all of the jack pines?," there were many instances where the teacher needed to move the class forward with more direction when student questions were insufficient to do so. During one of the classes the instructor commented to the observer, as an aside: "the only problem with the inquiry method is that if students don't ask questions nothing happens!"

  The expected differential impact of telling vs. asking is illustrated in the case of how the stochastic nature of the model was introduced. In two different sessions the instructor asked students to run the simulation under identical conditions and compare there results. In one context he then explained that their results differed due to the randomness build into the model. In the other case he asked “Why would the results be different?” and engaged students in a short discussion. In both contexts there was a later situation in students needed to use their understanding about the stochastic nature of the model. Students who received the verbal explanation were not able to correctly apply this knowledge and had to be reminded; some of them did not even remember that the simulation had random characteristics. Students who were asked to discuss it *were* able to recall and use this information; one student's response was "because there is randomness in the model to account for the randomness in nature."

- We observed **pre-telling** ("you will soon discover that..."), **pre-asking** ("How can we answer this question using the simulation?"), **post-telling** ("what you just learned is..."), and **post-asking** ("What can we learn from what we just saw?") tactics. It seemed that pre-telling and asking was used to prepare, prime, or scaffold an activity or discussion; and post-telling was used to summarize or re-frame an activity or discussion.
- **Opportunistic flow of activities**. We observed the instructor dynamically creating or choosing activities based on the following: student questions, student need to know, results of a previous activity, and unexpected problems with the software. As noted elsewhere, this level of flexibility may be heavily dependent on the teacher's level of subject matter knowledge.
- **Committing to a hypothesis**. The instructor often asked students to pose a hypothesis or guess at an answer before starting an investigation. There were also instances of structuring a class activity based on testing a hypothesis randomly posed by an individual student. Beginning with a hypothesis in not only "good science," it can create more student investment and engagement.
- **Convergent and divergent episodes.** As mentioned every class could be described as a cycling between divergent individual simulation-based work and whole-class convergent consensus-building discussion. However, the simulation-based work also varied between exploratory open-choice activities and more systematic inquiry experiments.

4.3.3 Planning Activity Sequences

In this subsection we discuss more global, often but not necessarily pre-planned, strategies that involve the sequencing of activities and subject matter topics in a class (as opposed responses within a particular activity, discussed in the last subsection).

From our observations we found evidence that the following related factors are used activity sequencing: degree of background knowledge, time limitations, desired level of scaffolding, and level of open-endedness. The overall goal is to maintain learning as much within a "zone of proximal development" (Vygotsky 1970) for the class as possible, by providing the correct amount of challenge without overwhelming or confusing students. This is primarily done through scaffolding, and later fading away the scaffolding (Brown et. al 1984). Scaffolding an activity can take several forms: 1) providing extra information or hints, and 2) constraining the complexity of a task.

The scaffolding could be pre-planned but is often done dynamically. For example, in Trail 4B2 the instructor initiated several inquiry cycles, each of which were essentially sub-goals of the original challenge, helping the students by breaking the original problem into more manageable steps.

The instructor tried to design activities to insure success and encourage ownership. One tactic for this was to start an activity with questions. The instructor began many sessions by asking questions such as "how do trees get their energy?," soliciting student responses and encouraging students to justify answers and take a stand on the issue. Sometimes this served as a lead-in to a mini-lecture on some concept, and at other times it served as a way to anchor student inquiry activities.

The most interesting patterns we saw for activity sequencing involved organizing the class for collaborative problem solving, sometimes called the jigsaw method, as described next.

4.3.4 Collaborative Inquiry and Distributed Problem Solving

We observed teaching methods that repeatedly brought the entire class in to collaboration around the inquiry, after individual or small group activities. Simulation-based software provide rich a rich environment for such collaborative inquiry. This is due to several factors: the abilty to rapidly run experiments allows students to go through cycles of trying something and coming back together to discuss it with a frequency that maintains active dialog; 2) it is relatively easy to set up initial conditions, thus making it easier to carve up organize a search space amongst participants; and 3) the graphic nature of the simulation provides something for students to refer to concretely as they discuss their observations and ideas.

Alternating convergent and divergent activities. The instructor was facile with a spectrum of open to closed activities, and usually ran the class as a progression of convergent whole class episodes and divergent simulations-based episodes. For example, in trial 2B the instructor lead the students though several cycles of divergent exploratory work, systematic inquiry experiments, and convergent consensus-building activities.

Additive knowledge. The entire class is given a very open ended task, such as "run the simulation and note what you observe." The class then reconvenes to share what they learned, compare, synthesize, and combine findings. This allows each student to benefit from the collective observations and insights of the whole.

Breadth search. In a related method, each group is allowed to pose their own inquiry question and investigate. When they reconvene students are exposed to issues and information beyond what they would have had time to explore on their own.

Simulated annealing. In computer science there exists a search strategy called simulation annealing, in which a certain amount of randomness is introduces to an otherwise systematic search to avoid the problem of local minima. Simulated annealing serves a an apt metaphor for a collaborative inquiry strategies that we observed in which students were allowed to explore a parameter space unsystematically. For example, in Trail xx students were asked to "play with the simulation" to try to find site conditions that favored white pine. In this type of unconstrained exploration, it is hoped that at least someone in the class will come near a solution. It is usually then followed by a more systematic approach as described below.

Jigsaw method state space search. We saw several cases of the instructor dividing a search space and assigning components of it to groups. For example in Trail XX the instructor organized a systematic exploration of a multi-variable space of temperature, soil quality, and rainfall conditions, asking each group to chose one of these to vary which keeping the other parameters fixed at a value that, through a simulated annealing method, was found to be close to a solution.

Collaborative hypothesis confirmation. Finally, we observed several sessions (see Trail 4A1 for example) in which the instructor assigned groups with conditions to test alternate hypotheses.

4.3.5 Miscellaneous Findings

Context and prior knowledge. We found multiple evidence for the importance of background knowledge in doing simulation-based inquiry. Background knowledge varied among the trials. In the clinical sessions the students were not in a botany course. In some of the clinical sessions the instructor started with a mini-lecture on botany, while in others he started right in with simulation activities. In the classroom-bases sessions there was a variation in the number of weeks of class that the students had before the trial began.

Lack of knowledge in botany seemed to make it more difficult for students in clinical sessions to understand the implications of the simulation. In contrast, students in courses were more capable at manipulating and interpreting the simulation in order to complete their investigations. Overall, they appeared to be more motivated and excited about using the simulation. Also, Students' prior knowledge and experience with forest ecology affect their ability to ask questions. Students in the classroom context readily introduced questions such as “What will happen if we take out all of the jack pines?” or, “Once the jack pines die out how can we make them come back?” In contrast, in the clinical sessions, when asked when asked, “What kind of questions might a scientist investigate using this software?” there was only a minimum of engaged response.

Individual vs. group work. often one student would dominate in a pair. However, it is possible that both students were learning. Switching who was "driving" the simulation sometimes helped, but a more effective method seemed to be to have students take roles, with one operating the simulation and the other recording notes and data.

4.4 Generality of Case Study Results

A question naturally arises as to whether the suggestions based on this case study are applicable to other instructors. Our primary evidence in this regard comes from our relatively successful attempts to integrate SimForest into secondary school classes, as described a later Section. One of the primary characteristics required is flexibility on both local and global levels. At a local level is the ability to respond to student questions, which in open-ended learning are more unpredictable than in more pre-planned classes. At a global level is the ability to select or create each next activity in a way that flows from the classes current needs or questions. Flexibility at both levels seems due mainly to two things: teaching style and domain knowledge. The flexible teaching style needed to run open ended inquiry style classes has been widely written about (see references in Section 2), and has been called "constructivist," "guide on the side" (vs. sage on the stage), etc. As discussed more later, these skills do exist in many educators, and can be taught to others, though the process involves gradual and sometimes fundamental changes.

Knowledge level is also important, in particular in this case the instructors knowledge of the expected behavior of various tree species. The ability to adapt locally and globally that is illustrated by our expert requires a great deal of botany and forest ecology knowledge, and a confidence in that knowledge. This may limit the ability of a teacher to *invent* new activities on the fly. However, our secondary school teachers were quite able to plan inquiry activities ahead of time for their students and make minor adjustments during the class as needed.

Finally, we conclude that knowledge of how to run the simulation is not as important as the other factors mentioned. Our secondary school teachers gained this knowledge with out problems, though it did take effort (in the Summer Institute),

5 Evaluation of Secondary School Implementation and Professional Development

The professional development part of our project involved holding a one week institute for eight secondary school teachers in the summer of 2001, visiting them in their classrooms as they incorporated SimForest Lessons over the next two semesters, and holding 5 quarterly day-long meetings to bring the group together do debrief, teach each other, and plan. The "Summer Institute on Educational Software for Inquiry-based Science" that was held at Hampshire College from July 16-20, 2001. Eight teachers from the Pioneer Valley attended the professional development (PD) workshop.

Table 3 shows an overview of the eight participating teachers and their classes in six locations. Two of the locations had two teachers. There were two high school teachers and the rest were middle school (except one who was transferred to an elementary school at the last minute). Two of the teachers were technology teachers and the rest were general science teachers, except for one of the high school teachers who was a chemistry teacher (with a strong inquiry focus in his class).

Table 3 Overview of Classes

Teacher	Location	Grade	Class name	Duration	#Students	StuDataAn
Paula	Longmeadow	7th & 8th	Science	2 weeks +	25, 14	Yes
Peggy	Longmeadow	7th & 8th	Science	2 weeks NC	14, 13	Yes
Diana	Chicopee	8th	Science	2 weeks	22, 24	Yes
Samantha	Chicopee	8th	Technology	2 week	25, 18	No
Kathy	Turners Falls	9-12 mixed	Computer Literacy	3 weeks NC	18, 22	No
Phil	Northampton	9-12	Chemistry		72 total	N/A
Jack	Amherst	8th	Science		~60 total	N/A
Carol	Leominster	7th	Science		75 total	N/A

Three of the teachers who attended the summer institute were not able to use the SimForest software and curriculum in their classes (though two of them, Phil and Carol, had some of their students download it and try it at home). Phil encountered a long series of very frustrating problems with computer hardware and availability in the computer labs in his newly renovated high school, which lasted for two semesters. Carol was transferred to another school at the last minute before the fall semester, and both a combination of hardware problems, the demands of the new job, and lack of support from the administration at the new school resulted in her inability to incorporate SimForest. Phil underestimated the demands of starting to teach at a new school and dropped out of the project soon after the semester started. Phil and Carol continued to maintain interest and enthusiasm in the project despite their inability to adopt it, and cam to our periodic group meetings keep in touch via email. For these teachers the table shows the total number of students in their science classes who were exposed to inquiry-based methods.

In the end five of the eight participants used SimForest in their classes. They all did so for both the Fall and Spring semesters, in two of their classes in each semester. As is shown in Table 3 most of the teachers used SimForest for two weeks. "NC" in the Table means that the SimForest sessions were not consecutive. In these cases SimForest lessons were done something like once a week for a number of weeks. Most of our data was taken during the Fall semester (this is because the research assistant working on the project spent most of the Spring semester analyzing the data and writing her thesis). The Table shows the number of students in two Fall classes. The Table also shows that we focused our analysis of student inquiry skill gains on three of the classes.

Description of the participants. Of the high school teachers Phil Smith (this is an alias, the names of teacher participants have been changed in this report) is a chemistry teacher at Northampton High, and Kathy Cannon is a technology teacher at Turners Falls High. The other six teachers were middle school teachers, Samantha Parker is a computer teacher at Fairview Veterans Memorial Middle School in Chicopee. Diana Smith is a science teacher at the same school in Chicopee. Another pair of teachers from the same school were Paula Nichols and Peggy Taylor, both of whom teach science at Glenbrook Middle School in Longmeadow. The remaining two teachers are science teachers who both began teaching jobs in new schools the semester after the summer program. Jack Wilson moved from West Springfield to Amherst, and Carol Gardner moved from Athol Royalston Middle School to Southeast Elementary school in Leominster (the need for this relocation was not known to her until shortly before the school year began.

All of the teachers except Diana Smith attended the entire week long workshop, and they were each awarded "professional development points," as well as a stipend of $450 dollars for their time (Diana attended the last day of the workshop, and caught up quickly with the help of Samantha Parker). The agreement was that they would be given an additional $450 dollars after they had completed the SimForest project in their classes for two semesters.

Overview of the summer institute. Throughout the weeklong workshop, there were various activities planned, and times for discussions on ecology, inquiry-based education, an overview of the Massachusetts Science Frameworks, designing assessments, adapting individual lesson plans, and of course familiarization with the computer program. We left a good deal of time for feedback and discussion of how the workshop was going for each of the teachers, and adjusted our schedule and reorganized pre-planned activities in order to meet the needs and interests of the group. (For detailed agenda, see Appendix).

5.1 Evaluation Methods

Below we summarize the types of data gathered for this study:

- **Daily Summer Institute Session Evaluations.** Participants completed a questionnaire at the conclusion of every day of the Summer Institute. This was used for two purposes: to tailor the next days sessions according to feedback, and to monitor their changing attitudes for evaluation purposes. (The instrument is shown in Appendix 8.3.3.)
- **Summer Institute Final Evaluation.** A questionnaire, shown in Appendix 8.3.4 was given to participants at the end of the summer institute to asses its quality.
- **Teacher Questionnaires.** Teachers were given an attitude questionnaire for times: before the summer institute, after the summer institute, after the first semester of using the software, and after the second semester of using the software. (The instrument is shown in Appendix 8.3.5.)
- **Teacher pre and post Interviews.** We held individual interviews with the teachers before the summer institute, during the summer institute, and at several times while they were using the software. Data from these interviews consisted of field notes. (See Appendix 8.3.8 for the interview rubric.) Included in these notes are notes from random informal conversations with teachers at times other than the official interviews.
- **Teacher Journals.** Teachers were asked to reflect on their experiences and lessons learned after every class related to the SimForest project. (See Appendix 8.3.7 for instructions given to the teachers.)
- **Teacher Retrospectives**: Teachers were asked to write a retrospective at the end of each of the two semesters.
- **Classroom Observations**. Galton and Murray conducted a number of observations of classrooms in which SimForest was used. (See Appendix 8.3.6for our observation rubric.)
- **Student inquiry skill pre and post tests**. Students in the classes were administered pre and post tests to measure changes in inquiry skills. (The instrument is shown in Appendix 8.4.1, and the analysis rubric in Appendix 8.4.2.)
- **Student work**. Student worksheets, lab reports, and homework assignments from several of the classes were collected.

5.2 Results of Secondary School Trials

5.2.1 Description and Evaluation of Summer Institute Sessions

After six of the Summer Institute sessions the participants were given the questionnaire shown in Appendix 8.3.3. The questionnaire was given after the following six sessions (see Appendix 8.3.1 for a complete syllabus):

A. Monday #1&2: Into The Woods
B. Monday #4: Intro To the Software
C. Tuesday #1: Software cont.
D. Tuesday #3: Assessment
E. Wednesday #1-4: In depth Software use & MA Frame-works
F. Thursday #1: Inquiry Learning Discussion

Questionnaire items 1-5 were mainly to help us adapt the next day's syllabus plans. Below is a summary of the responses for questions 6 and 7.

Table 4 Daily feedback on Summer Institute Workshops

		A	**B**	**C**	**D**	**E**	**F**
Q-6) As a result of this session I feel (select answer) with the **inquiry method** of teaching	More Comfortable	4	5	5	2	6	4
	About the Same	3	2	1	4	1	2
	Less Comfortable	0	0	1	0	0	0
Q-7) As a result of this session I feel (select answer) with **integrating the SimForest** model into an activity in my classroom(s).	More Comfortable	3	4	7	3	7	3
	About the Same	1	2	0	2	0	3
	Less Comfortable	0	1	0	1	0	0

Below we will discuss this data and in doing so give a description of many of the workshop sessions.

There were six sessions that were evaluated in this format. "**Monday 1 and 2** Into the Woods" refers to the first two sessions on Monday morning when the entire group headed out into the woods, and had some lessons in forest ecology, led by Larry Winship, the botanist in the SimForest program. The time spent in the woods was modeled as an example for the way one of the teachers could bring their own group of students out into the forest. There was some time spent observing and discussing what people could see—what actually made up the various parts of the forest. Larry helped the teachers identify some of the tree species and spoke about some of the qualities of different trees. We also broke into pairs and were each given a circle of string to place on the ground—claiming our own plot of forest. We then spent some time writing about what was in our plot and then shared with the larger group. After the session in the woods, four of the teachers felt more comfortable with the inquiry model of teaching, and three of them felt "about the same," meaning the same as they had before the workshop. No one felt less comfortable. Three teachers felt more comfortable integrating the SimForest model into their classrooms, and one teacher felt about the same. Again no one felt less comfortable, but not all the teachers responded to that subject—some of them felt it was not applicable to answer.

"**Monday 4** Intro To Soft-ware" was the first session after lunch on Monday where the teachers were able to open the program and begin to play around with it. Again this session was facilitated in a model way to how teachers could first introduce their students to the program. Five teachers felt more comfortable with the inquiry model of teaching, two felt about the same as they had before, no one felt less comfortable. Four teachers felt more comfortable with integrating the SimForest model into an activity in their classrooms, two felt the same as they had before, and one person felt less comfortable. This definitely indicates the amount of frustration that one of the teachers had with the non-scaffolded approach to becoming acquainted with the different possibilities of the SimForest program.

Tuesday morning the first session was continuing working on the program, starting off where the group left off the first afternoon. For their comfort level with the inquiry model, five teachers felt more comfortable, one stayed the same, and one teacher felt less comfortable after that workshop. All seven of the teachers indicated that they felt more comfortable with the idea of integrating SimForest into their classrooms, after that session.

Tuesday afternoon we had a discussion on various ways to assess student work and learning. Paul Zachos was the guest speaker for that session, and many of the teachers became confused as to how this was relevant to the rest of the workshop. There were mixed results to their feedback on this session, and we could tell from their verbal communication that they did not enjoy it as much as the rest of the sessions. In terms of their comfort level for the inquiry model of instruction two of them felt more comfortable after this session, and four of them felt about the same as they had before. Three of the teachers felt more comfortable integrating SimForest into their lessons, two felt about the same as they had before, and one teacher felt less comfortable.

At the workshop on **Wednesday** the teachers spent more time working on the software, and there was a discussion about the Massachusetts State Frameworks, which focused on how the SimForest program could fit into those frameworks. The teachers filled out one evaluation form that encompassed the whole day. Six teachers felt more comfortable with the inquiry model of teaching after those sessions, and one teacher felt the same as they had before it. All seven teachers felt more comfortable with integrating the SimForest model into an activity in their classrooms. This reinforces what we had already concluded, which was that they simply needed more time to explore the software in order to feel confident of their ability to use it as a learning tool in their classes. Wednesday was the first time that the teachers used the Glass box version of the software and they were impressed with most of what it had to offer, and they began to think of ways to shape classroom activities around the program.

Thursday morning, the last session that we had evaluated in this format, we had a discussion about Inquiry Learning. After this session four of the teachers felt more comfortable with the inquiry model, and two felt about the same as they had before. A few of the teacher participants came to the program with very strong backgrounds in using the inquiry model, which of course influenced their responses on this evaluation form. Three of the teachers felt more comfortable with the idea of implementing SimForest, and three of them felt the same as they had before the discussion.

In general it seemed that people's comfort level both for implementing SimForest and with inquiry teaching went up. There were only three sessions when one teacher responded that they felt less comfortable, and except for the discussion on assessment, we always addressed those concerns in future sessions, so by the end of the institute the teachers felt more confident with the program and teaching inquiry.

5.2.2 Post-evaluation of the Summer Institute

Appendix 8.3.4 shows the evaluation questionnaire given to participants at the end of the Summer Institute, and give details of the data, including comments written. The results are summarized in Table 5, which shows the average response among the participants from 1 to 5 (strongly disagree to strongly agree) Likert scale items.

Table 5 Summer Institute Post-evaluation

	Ave. score
1. I **met my objectives** for attending the Institute this week.	4.5
2. It was beneficial to share and **learn from my colleagues**.	4.4
3. I **would recommend** this type of professional development to others.	4.5
4. The **topics** covered in the workshop were **appropriate** and useful to me.	4.4
5. The computer **software was easy** to use.	3.7
6. The workshop **materials** (handouts, articles, software) were useful.	4.0
7. The **presentations** were clear and easy to follow.	4.4
8. The **facilities** and arrangements were good (directions, food, location, etc.).	4.9

9. I had **enough time** for reflection and question asking.	4.9

The statements all received very high score. The only item with an average response below a four was "the computer software was easy to use" which was 3.7. Most of the teachers agreed strongly with the statement that they would recommend this type of professional development to others. As mentioned above, we were attempting to make improvements in two challenging areas: the use of simulations in the classroom, and the adoption of inquiry methods. As the material that we were trying to teach was a significant "stretch" for all of the teachers involved, we conclude that the structure and content of the institute was effective overall.

5.2.3 Effects of the PD Intervention on Teachers

We administered an attitude questionnaire to the teachers several times during the course of the project: before the institute, after the institute, after one semester of teaching, and after two semesters of teaching. The questionnaire, shown in Appendix 8.3.5, asked teachers to rate: A) comfort & confidence level, B. understanding & skill level, and C) classroom use & adoption level, on a scale of 1 (high) to 5 (poor), for each of the following six questions:

1. Teaching scientific inquiry skills (in general)
2. Using simulation-based software in your classes (in general)
3. Teaching botany and ecology content related to your classes
4. Designing and using student assessments in your classes.
5. Using SimForest in my classes
6. Using or Adopting SimForest curriculum for my classes

The data is summarized in Table 6, which shows the responses averaged over all teachers who were participating at the time (note, data from the final round of questionnaire is not included yet). Some cells in the table are blank because the corresponding questions were not appropriate until the teachers started suing SimForest in their classes.

Table 6 Teacher Attitude Changes Over One Year

Q	**Pre-SI**	**Post-SI**	**January**	**Pre-Post Δ**	**Post-Jan Δ**
A . Comfort & Confidence					
1A	2.17	1.5	2.25	0.67	-0.75
2A	2.83	2.25	1.67	0.58	0.58
3A	2.67	2.188	2	0.482	0.188
4A	2.17	1.94	1.5	0.23	0.44
5A			1.75		
6A			2		
B. Understanding & Skill Level					
1B	2.17	1.75	2	0.42	-0.25
2B	3.17	2.375	1.67	0.795	0.705
3B	2.67	2.188	2.25	0.482	-0.062
4B	1.83	1.75	1.5	0.08	0.25
5B			1.75		
6B			2.25		
C. Use & Adoption in Your Classes					
1C			2.125		
2C			1.83		
3C			3.25		
4C			1.25		
5C			2.25		
6C			2.25		

Perceived comfort/confidence and understanding/skill levels increased over the course of the institute, as would be expected. There was a drops in average scores between the institute and after the first semester for item 1: "Teaching scientific inquiry skills (in general)." This is probably due to the fact that for some of the teachers the reality of incorporating this type of inquiry curriculum into the classroom was more difficult than they expected. Also, there is probably a "feel good" effect that inflated the scores from just after the summer institute. However, the scores shown after the teacher's first adoption of the curriculum is high, in the 1.25 to 2.25 range, except for item 3C 3, the "adoption and use" of "Teaching botany and ecology content related to your classes." This is probably because the teachers did not feel that that covered very much botany, forestry, and ecology content in the limited number of lessons they had to use the curriculum.

From this data and from our interview data with teachers we concluded that the intervention was successful in terms of: 1) the teachers' learning how to incorporate inquiry and simulation-based methods; 2) their ability to adopt and adapt the SimForest software and curriculum; 3) their satisfaction with the experience and intentions to continue to use SimForest.

5.2.4 Classroom Implementation Case Studies

In this section we will describe the experiences of several of our participants as they implemented SimForest into their classes.

[This Section will be completed later]

5.2.5 Classroom Implementation Lessons Learned

Section 3.3 enumerates our recommendations for effective professional development. Below we mention some other observations and lessons from our classroom implementations (note: We have not finished analyzing the data from teacher interviews and journals.):

- We saw numerous instances of teachers learning from each other and supporting each other through the opportunities to come together that our project provided. They commented frequently on the importance if this aspect. The participants formed vibrant learning community, and social times at breaks during out workshops and meetings were lively.
- It was particularly useful to have two sets of teachers in two of the schools. In both cases one of the teachers was quite competent and confident with the approach. In one school the other teacher was an technology teacher who was supported by her peer's science background. In the other school the second teacher was not as comfortable with technology or open-ended inquiry as the first teacher, as received support in this regard.
- Though the teachers expressed a desire to keep in touch through an email list and web site postings, in reality they had little time to do this. The opportunities created by coming together regularly (which was part of the program for which they received a stipend) were essential in building the community.
- We consider our open-ended approach to PD to have been very successful. Rather than prescribe what they should do we offered the participants samples, model lessons, and suggestions. They took these and, with each other's input, developed a very diverse set of activities that met each of their individual needs.
- The importance of the logistical aspects of the intervention, including computer availability and administrative support, can not be overemphasized.
- Teachers took additional initiatives inspired by their SimForest project experience. One teacher who was taking a graduate evening class created a pre-post evaluation instrument for her students using the SimForest software, used it, and wrote a report about it. Two teachers plan to lead professional development workshops around SimForest themselves, in their own school districts.
- Two teachers plan to give a presentation of their experience at science teacher conferences.
- It was difficult for some teachers to "keep track of all the paper" and logistics in administering multiple versions of the inquiry skills pre and post tests, and related data organization (for instance

we asked them to assign unique Ids to students and send us information about these student's gender and class final grades).

- It was useful having two non-science (technology) teachers involved. They were not constrained by the content and time limitations of the state mandated Frameworks, and were able to do more extended and creative activities. One of them in particular based a large part of her semester on the SimForest subject. Though only a couple of weeks was spent using the simulation, she also had students creating multimedia field guides and multimedia public service announcements to "save the forests." The SimForest subject matter became the center of activities that involved learning about spreadsheets, desktop publishing, graphics, digital imaging, and digital video.

5.2.6 Changes in Student Inquiry Skills

In the five classes that used SimForest we administered a pre and post test for general inquiry skills. The test, designed by our research team, is included in Appendix 8.4.1. Appendix 8.4.2described the rubric used to code the tests. Our analysis focused on only three of the five teachers who used SimForest. We focused on the three middle school science teachers. The other two teachers who used the software taught technology classes, and did not focus as much on the inquiry process in their classes.

Students in each class were given a pre-test and a post-test.[7] Three versions of the test were created and assigned randomly to the classes. Because we were not confident that the logistics of assigning tests randomly *within* each class were tractable, all students in a given class were given the same version of the test. The three versions, used scenarios called "Fish," "Flowers" and "Worms," which had parallel structure. A situation is described, ending with a question. Part A asks the student to state a hypothesis. Part B asks the student to describe an experiment for testing the hypothesis. Part C says "Explain why your experiment is a good way to test your prediction." Part D says "Imagine that you predicted what would happen correctly. You decide to make a graph of your data. On the graph below put some made-up data that agree with your prediction." Part E says "Now, imagine that you repeated your experiment but got different results. You used good materials and recorded your data correctly both times. Give reasons for how that could happen." Part F describes an experiment done by someone else, with a table showing how two variables were manipulated in six experimental trials. The experimental design shown in the table is flawed because both of the independent variables are changed in each trial. The instructions say "You think there is a problem with their experiment. Explain the problem and how you would fix it."

We are analyzing data from three teachers, six classes, with a total of 112 subjects (see Table 3). The data is still under analysis (which will be re-run after adding data from one more class). Preliminary analysis has yielded the following results:

- There were no significant difference among the three versions of the test
- Question A (stating a hypothesis) was the only test question to show significant gains from pre to past test.
- None of the questions or the individual scoring items showed a significant decrease.
- Almost no one got item C correct.
- Looking at individual scoring items, we can see sub skills and their changes. (In a later paper we will describe individual sub-skill achievement.)
- Looking at individual teachers, only Peggy's class showed significant improvement on any question other than A. Here students showed a significant increase on question 2.
- There no gender differences have been seen yet in the analysis.

Conclusions about this data will be given after further analysis.

[7] Because some teachers planned to use SimForest in continuous classes and some planned to spread SimForest use over several weeks, we also administered a third test to the students.

6 SimForest-G and Glass Box Simulations

In this section we discuss SimForest-G, a prototype glass box version of SimForest-B that has not been tested yet. We also discuss the general issues of glass box simulations. A beta version of the glass box version of SimForest ("SimForest-G") is complete and has undergone some trial use, but it is still incompletely developed and evaluated. SimForest-G, both a forest growth simulator and an open-ended modeling environment, is a much larger and more complex program than SimForest-B.

Importantly, the glass box and open box modeling features of SimForest-G are domain independent. The software was designed to be a domain-independent glass-box modeling environment onto which one can add a user-interface to create a simulation in any domain. We call this domain independent module "SimGlass." SimGlass is a generic modeling tool for models that can be defined with sets of difference equations. If the user is to interact with only numbers, equations, static graphics, and dynamic graphs, then the designer does not have to build an extra interface component. The student or teacher can create a glass box simulation simply by authoring a mathematical model using the tools provided. But, as in the case of SimForest, if a goal is to provide an interactive visual simulation, then a programmer must code the domain-specific GUI component that communicates with SimGlass via a standard software interface (as we did with the interface shown in Figure 1). The SimGlass and SimForest-G software are written in Java and run on multiple platforms. See http://ddc.hampshire.edu/simforest for information about the project, or to download the software.

6.1.1 Background

Computer modeling is increasingly used in scientific research and theory formation to generate the data that is eventually used in public policy decisions (as in environmental impact studies). Understanding the nature of computer simulations and models is important not only for those studying or working in quantitative academic subjects, but also to succeed as workers and citizens in a society with increasing dependence on technology and science. Understanding the models or systems that produce biological, physical, social, or chemical behaviors is often a complex undertaking. In addition to a basic understanding of relationships and models, students need a working understanding of more sophisticated general concepts which may include feedback loops, the calculus of change, emergent properties, behavior in the limit, dynamic equilibrium, stochastic processes, chaotic and non-linear behavior. Most simulations illustrate phenomena and allow users to control processes, but do not by themselves directly support the understanding of the general concepts mentioned above. Our goal is to produce tools and techniques that make these concepts more easily understood, and allow for a critical and comprehensive understanding of the particular model being used. Our methods will allow for both novice level familiarity and in-depth understanding of a model, thus allowing simulations to be more useful to a wide range of user or learner backgrounds and goals.

Straford [1997 pg. 4] notes that "creating and running dynamic models should help clarify one's own mental models and foster deeper understanding of complex systems." Below we will describe how simulations fall within the categories of black box, open box, glass box, and free-box, and explain our focus on relatively unexplored but potentially very powerful technologies using "knowledge based glass box" simulations. The term "glass box" model and the concept of inspectable models are not new [Wenger 1988, Elliot 1978]. However, insufficient research and development has been done to flesh out 1) the important pedagogical and cognitive issues in supporting the understanding and use of glass box models, 2) the software methods and features needed to make glass box simulations educationally powerful, and 3) best practices for curriculum and instructional strategies for learning with glass box models. Our results will relate to on-the-job performance support and life-long learning as well as to more traditional educational venues.

6.1.2 Black-, Glass-, Open-, and Free-Box Models.

Embedded in every simulation is a model of some real or imagined process.[8] Because computers can rarely simulate reality precisely, every simulation includes substantial and significant assumptions and limitations affecting its accuracy and reliability. The vast majority of commercially available educational and professional simulations are "black box" simulations, in which the underlying model is hidden from the user. Sometimes this is appropriate, as when the goal is to discover what the underlying relationships are as if one was performing an experiment in the "real world." However, there are many contexts in which it would be beneficial to "open up the hood" and expose the underlying model to the user.

As a first step the learner should be able to *inspect* the model-- look at its component parts, observe the internal properties and variables of the simulation as it changes ("runs"), and inquire as to the nature or reason for each component. The term "glass box" has been used to describe such inspectable simulations. At a more complex level, the learner should be able to *modify* the model or build a new or alternative model. These might be called "open box" simulations. We usually use the more common term "glass box" to refer to models that are both inspectable and modifiable (but we distinguish glass box from open box when we need to distinguish the inspectable from the modifiable capabilities). Making simulations more transparent or self-explanatory has obvious benefits for mathematics, engineering, and science students. But, in addition to the educational benefits, simulation transparency will allow those using simulations at work or home to better understand and use them. This is important because our increasing dependence on esoteric and opaque technologies tends to be disempowering to the average citizen.

The importance of knowing how to interpret and construct computational models has been emphasized and researched by many, starting perhaps with Papert's work with the Logo programming language [Papert 1980]. Such modeling and programming environments are glass box simulations in a way, as the underlying model is by definition explicit and malleable, but we prefer to call them "free box" simulations. In free-box environments the learner builds a model from scratch, and in most educational contexts is limited to simple models and "toy domains." The predominant use of some of these systems focuses on domains where complex emergent behavior can be created by attributing simple rules to numerous component pieces (as in schools of fish). This is a pedagogically powerful approach, but many important phenomena and domains can not be approached with this method.

Black Box Simulations	**Glass Box** Domain-Specific Simulations	**Free-box** Modeling Systems
Ex: SimCity	**Ex: SimForest**	**Ex: Logo, Stella**

"Knowledge based glass box" models have the following important characteristics:

- Learning proceeds from a full working model which can be inspected, decomposed, modified, and added to.
- Each equation (element of the model) has pedagogically relevant information associated with it. This directly supports domain specific leaning of key concepts in the model.

6.1.3 Glass Box Forest Simulator and SimGlass

SimGlass is a domain independent glass box modeling environment---a general tool for building, editing, and inspecting equation-based simulations. SimForest-G is a glass box simulation created by starting with SimGlass, using its tools to define the variables, data tables (three of them), and equations (about 25 of them) that constitute the forest model, and finally programming (in Java) a forest visualization interface similar to the one in SimForest-B. The tools shown in Figure 6 and 7 are components of SimGlass, and are thus available to all glass box simulations built with this system (including SimForest-G).[9] The model

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[8] By "model" we mean the equations, rules, relationships, or procedures that determine the behavior of the simulation (they can be quantitative or qualitative).

[9] SimForest-B was programmed using Macromedia Director. SimForest-G and SimGlass are programmed in Java. The Java application has a more flexible and powerful underlying simulation engine with the

inspection tools allow the learner to "look under the hood" of the simulation model and see the equations underlying it. Users can browse to learn about the meaning and theory behind important parameters, see the connections and interdependencies between model variables, and track the values of variables as the simulation runs.

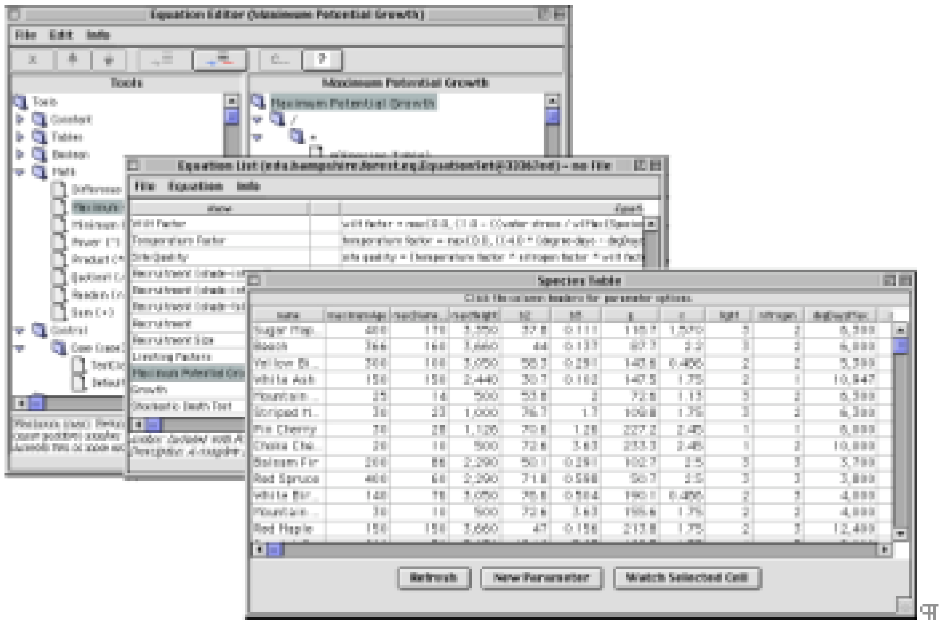

Figure 6 A,B,C: SimForest-G Model Editor, Equation List , Species Table

The Inspector provides a consistent framework for accessing multiple representations of formulaic relationships (based on multiple epistemic forms as described in [Collins & Ferguson 1993]). It enables students to observe the results of equations, compare equations, and explain phenomena in terms of equations (essential to inquiry investigation, Tabak et al. 1996). The software supports easy navigation from reference to referent (e.g. if an equation contains a variable defined in another equation, the user can easily navigate between these two equations). The following types of information are associated with each equation and variable: description, units, referents, assumptions, and limitations, graphic illustration, alternate versions.

The model *editor* tools allow the learner to alter the model by changing or adding variables, parameters, and equations. It is a full featured modeling tool and a simplified programming language of sorts.[10] While equation inspection allows learners to learn concepts and principles in the model space, the equation editing allows learners to do inquiry in the model space. They can test their hypothesis by changing parameters that embody basic assumptions. In addition to modifying equations learners can load alternate versions of equations, as provided by teachers or peers, that embody competing theories (and see the discussion of "model progression" below). The editor includes the common set of algebraic, trigonometric, and Boolean operators, a conditional operator, composite operators (sum, SD, average, count), and a random number function. Model variables (stored in tables) can be constants or can depend on the results of equations. By giving the model access to values from previous simulation iterations we can perform iterative calculus (difference, slope, and integral computations). The modeling environment is quite powerful, allowing the creation of a wide array of simulation models in many domains (see Work Plan for domains we plan to implement).

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additional functionality mentioned, but as yet has a less sophisticated interface and is missing some of the fancier visual features of the Director version (such as 3D orthogonal perspective view of the forest).

[10] The current version uses a hierarchical representation of equations (Figure 3). This was the easiest to implement but we do not expect it to be as easy to use as more graphical network-like or WYSIWYG equation editing tools which we will include in future versions.

Table 7 Glass Box Equation Properties

Equation	SQI = (1-BAR)/BAMAX
Textual representation of the equation	Soil Quality Index = (1 - Total Basal Area)/Maximum Plot Basal Area
Description	SQI is soil quality index, which determines how the intrinsic fertility of the site limits the growth of trees. It is a measure of ... [text book or URL reference].
Units	(The units in which the variable is measured)
Graph of relationship	Picture showing qualitative shape of relationship
Referents	SQI is referred to in these equations: … SQI refers to these variables: …
Assumptions, simplifications, and limitations to the equation	The equation assumes that tree circumferences are perfect circles.
Alternative equations	For a more complex equation that takes into account circumferences that are not perfect circles, see …

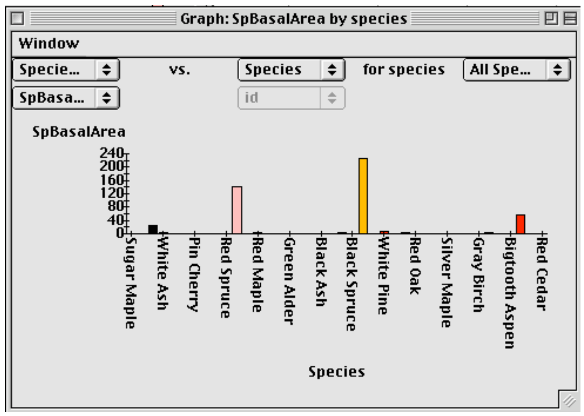

Figure 7 SimForest-G Tree Area vs Species Bar Chart

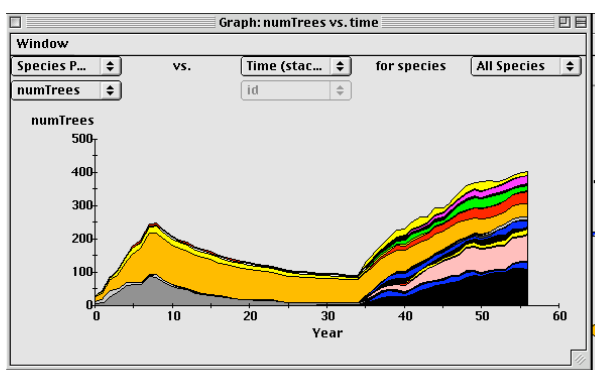

Figure 8: Tree Frequency Series

The SimGlass generic environment contains tools for plotting several different types of graphs to visualize any variable or equation in the model. Figures 6 and 7 show two of these graphs from the SimForest-G simulation. The software supports the learner in accessing multiple representations of information, which is beneficial in both educational and training contexts [Gerry 1991]. SimGlass has tools that allow the user to import and export data into Excel for further analysis. It has tools for tagging and monitoring variables of interest. Through the proposed grant project we will add the following capabilities to SimGlass: statistical averaging for population modeling; WYSIWYG equation editor, performance analysis and enhancement; hypothesis and experiment organizer; simulation pause through event triggering; qualitative graph-based equation manipulation.

SimGlass models can be built by students, teachers, and educational materials developers. It can be used as a fully functioning authoring tool [Murray 1999] for glass box simulations if the input and output variables of the model are to be visualized using standardized forms, tables, data sliders, and graphs (i.e. when no special graphical interface is needed).

6.1.4 Knowledge Based Glass Box Simulations.

Black box simulations, designed to promote learning in some specific subject area, are limited in the extent to which the learner can understand the underlying model, and do little to help learners understand modeling in general. Free-box environments allow learners to play at modeling, but can limit the learning to simple models that do not contain content that supports a deep understanding of a particular subject area. Our "knowledge based glass box" simulations (which include open box features) address these limitations. Starting with a fully functioning simulation and then allowing the user to inspect, take apart, and modify the simulation's model is more pedagogically powerful than either the black box or free-box approaches alone. Essential to our approach is an object-oriented representation of the model. Each model component (equation, rule, decision, or variable) is an object that can have pedagogically relevant meta-information associated with it, such as: its purpose, its derivation, diagrams or graphs to help visualize its nature, how it relates to other variables or components in the model, embedded assumptions or limitations, etc. When teachers or learners add or modify components they can include or modify model meta-information. Because the equation objects contain this meta-information, the approach is also a "knowledge-based" approach to modeling [Hoffman 1987, Brachman & Levesque 1985].

6.1.5 Comparison with Related Projects.

A number of other educational technology R&D projects have created software that deals with models and modeling skills, including Model It [Soloway et al 1997], Star Logo [Resnick et al. 2000, Wilenski & Resnick 1999], Stella [High Performance Systems], Boxer [diSessa & Abelson 1986], and AgentSheets [Repenning & Summer 1995]).[11] Each has its contribution. We will distinguish our approach, which we call "SimGlass," from these. All of these efforts (including ours) focus on providing computer modeling formalisms that allow students to construct models and observe simulations running. All of them can be used to observe complex phenomena and emergent behaviors, and try alternate versions of theories or models. All can be usefully applied to many STEM areas. All provide a modeling language, a user interface for setting and observing variables (usually with sliders and meters), and capabilities for graphing variables over time. AgentSheets, StarLogo, and SimGlass provide sophisticated animated renderings of the simulations (in AgentSheets and StarLogo the learner can author these). StarLogo's and AgentSheet's modeling paradigm uses a multi-agent local (or micro) perspective (e.g. programming the behavior of an individual fish, molecule, or traffic intersection, to be able to observe many of them interacting together). In Model-It learners express variable relationships qualitatively (as in "as X increases Y increases"). Boxer, AgentSheets, Stella, and StarLogo are as much programming languages as modeling languages, where learners program procedures or author scripts to define the behavior of graphical objects. Stella, Model-It, and Boxer provide graphical layout tools for visualizing the relationships (input/output or function calls) between variables. Though all of these projects include curriculum with pre-built models for learners to inspect and modify, they all incorporate a "learning through design" philosophy, where learners start out with a blank slate or very simple model, and learn through constructing an artifact [Perkins 1986]. Our approach has several differences with these other efforts:

1. There is pedagogical benefit from **starting with a full, complex simulation**, as in Sim-City®, Sim-Ant®, or a simulation used by professional engineers or scientists, with between 10 and 50 variables and as many equations. For example, our glass box SimForest simulation (described later) contains

[11] Other systems allow the *teacher* to create models, and students then learn within the authored simulation; but from the student's perspective they remain black box simulations (for example: SimQuest [van Joolingen & de Jong 1996, deJong & van Joolingen 1998], RIDES [Towne & Munro 1988], and ThinkerTools [White & Frederiksen 1995]).

approximately 25 equations for forest growth (from [Botkin 1993]). This may seem to be more complex than starting from scratch and building a toy model, but in fact it acts as a form of cognitive scaffolding [Collins et al. 1989]. This has several pedagogical implications. First, the simulation can be used as a more realistic context for scientific inquiry. With our SimForest simulation learners engage in authentic and sustained inquiry regarding the effects of disturbances on forest ecology. Second, we view models as systems of relationships that can be inspected one by one and *taken apart*. This contrasts with the method of starting from nothing or from a simple model and constructing or putting together. Both approaches have merit. The bottom-up constructionist approach, while being more meaningful to students who are successful, can lead to more floundering, and after much effort may lead to only simple models.

2. Our **pedagogical approach** is more analytic than synthetic, and allows the learner to interact with more authentic models of behavior, while still being able to practice modeling skills. For example, if we had asked students to build up the SimForest model from scratch, it would have taken months, and many students would have gotten lost along the way. Even an instructor, in preparing for a class, could not be expected to build a model this complex and accurate. But by starting with the full model, the instructor can start with scientific inquiry using a black-box, and then ask the students to open up the box to inspect and modify only those relationships that are the focus of the day's lesson.
3. We use the **knowledge-based** modeling method mentioned above. Unlike any of the other approaches, we provide meta-information with the model that allows the learner to inquire about each variable and equation. Thus pedagogically relevant information is associated with each equation and variable (this information can be authored by teacher or student).
4. Our modeling paradigm is a **set of equations** (usually difference equations). This differs from systems that model using functions, procedures, feedback loops, or qualitative relationships. Since equations can be included in functions and procedures, our modeling paradigm is more limited. However, it is closer to the paradigm used in most entry and mid-level science, mathematics, and engineering courses. Our pedagogical focus is on understanding the relationships between important variables in the model in a more classically mathematical style; not on developing programming skills. Again, the focus is more on analysis (and scientific inquiry) than on constructive design skills.
5. A final distinction between our project and others relates to our **research goals** more than to our modeling software. In all of the publications we have seen describing the other systems mentioned, there appears to be uninvestigated assumptions about the validity of the pedagogy. All that we could find were anecdotal evidence of the success of the systems in learning; stories of how the systems were enthusiastically used by students to build an engaging simulation or observe some surprising emergent phenomena. Our team, specifically the REAL research program at Hampshire College, has been conducting in-depth studies of inquiry learning, scientific visualization, and pedagogy though several other NSF grants. Based on the literature describing previous projects, and on our experience thus far with glass-box simulations, we are confident that our glass box approach is sound. However, we need to gather more evidence about what aspects of the software and teaching methods are most appropriate for various instructional contexts.

6.1.6 Pedagogical Issues

Our curriculum for using knowledge based glass box simulations uses a progressive series of tasks moving from a black box model to an inspectable model to a modifiable model. For example, with the SimForest system (described later) the glass and open box features are at first hidden from the user. Students perform inquiry in the black box environment, adjusting environmental conditions such as rainfall and soil quality, planting and cutting different tree species, etc., to investigate the effects of natural and man-made disturbances on the distribution and diversity of tree species. The curriculum introduces them to a number of factors and theories of tree growth, such as light competition and species succession. The back box simulation can be used to illustrate these concepts, or, through inquiry activities, students can be lead to discover them. At some point students inevitably start to ask questions about the simulation itself. Is it accurate? Which of the competing theories that we discussed is used in the SimForest model? Can we add a factor for soil heavy metal pollution to the model? Such questions set the context for "looking under the hood," and beginning to see the SimForest simulation, not as *the* model of forest growth but as *a* model of forest growth.[12]

Using SimForest students can look at the parameters and factors of the underlying biological model, and inspect the equations that relate these factors to each other. Some students or teachers may stop with model inspection, having gained an understanding of the inner workings of the model and the botany principles that the equations reflect. Some will go further by manipulating the model itself. They may see what happens if a linear relationship is changed to a parabolic one. They may add a new factor to make the model more precise, or remove one to see if a simplified model is just as accurate. Note that in our SimForest project all of these learning activities are supported by curriculum materials with sample lessons and instructional methods suggestions. The simulation environment itself supports stand-alone inquiry through the knowledge based approach, but in general a cognizant instructor will need to guide the learning.

Below we describe some of the issues that we have already identified. These illustrate our theoretical starting points and indicate the types of results we have thus far, many more of which we plan to investigate during the course of the project.

Emergent Properties and the Simulation Meta-Model Problem. Figure 8 illustrates what we call the "meta-model problem" for designing educational simulations. For any simulation model there exists both underlying assumptions of the simulation and emergent properties of the simulation that are not explicitly described in the model's equations, but may be important learning topics. Students using a glass box simulation can look at the equations that constitute the model, but they also need to be able to inquire about underlying assumptions or emergent properties. We incorporate features into our software that allow students to obtain information and learn at all three levels.

Assumptions, Sub-theory (e.g. chemistry)	-->	SIMULATION MODEL (e.g. biology)	-->	Emergent properties (e.g. ecology)

--> increasing model granularity -->
<-- answering "why" questions <--

Figure 9: The Meta-Model Problem

The knowledge-based representation of equations allows us to store descriptions of the **underlying assumptions** and derivations of each equation. Our analysis tools allow users to define the **emergent properties** that they want to observe and then produce graphs or data tables to learn about these properties. Examples from the SimForest domain are: 1) at the model level there is an equation relating tree growth to nitrogen content in the soil; 2) at the underlying assumptions level one can access a description of the biochemical explanation of this equation, or how it was empirically discovered;[13] 3) at the emergent properties level a student can define a new equation for Species Diversity which is the number of different species alive at any given time, and can graph this property over time. Species diversity and species succession are emergent properties of the forest growth model. The simulated forest exhibits these properties but they are not referenced in the model itself (unless the student creates them).

Supporting Inquiry Question Types. Students and practitioners engaged in inquiry about natural phenomena ask a variety of types of questions [Collins & Stevens 1993]. Our goal is to support

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[12] This conceptual shift is an important learning experience for many students. In a general sense it marks a demystification of computer simulations, indeed of all software, so that these systems are understood more deeply to contain limitations and assumptions.

[13] Note that this explanatory level of information *must* be in canned text form. If it was represented in a computational way it would be part of the model itself. This would push the "why" question to the next deeper level, but a "why" question would still remain.

investigation in terms of these question types, listed in order of increasing cognitive sophistication and described in more detail in [Murray et al. 2001]: 1) Concrete/Situational ("What if?")--questions that deal with particular observable variables or situations; 2) Relationships ("How?")--relationship questions focus on the relationship between parameters of the system, and represent more abstract conceptual understating of the domain than the concrete questions; 3) Explanatory ("Why?")--for example "Why does increased soil quality decrease tree diversity?" These questions delve deeper into the causal relationships and underlying assumptions beneath the model; 4) Modeling questions -- dealing with creating new models or critiquing existing models.

Model and Activity Sequencing. One of our concerns is how computer models and educational activities should be sequenced for most effective learning. With SimGlass simulations learners can create or load different versions of equations or of entire models that embody competing or progressively more elaborate theories. This allows us to incorporate "model progression" methods [White & Fredeiksen 1986] in which the student is exposed to increasingly more sophisticated versions of a model, each new version being introduced at the "teachable moment" when the learner realizes that the previous model is insufficient to answer one of their questions. We will study how student's mental models [Gentner & Stevens 1983] of simulations correspond to the actual models. Also, we want to study the interaction of black box, glass box, and open box modalities. This progression is reminiscent of the sequence (or cycle) of 1) inquiry (simulation), 2) reflection (model inspector), and 3) generalization (model editor) mentioned in [White & Frederiksen 1995], but at a larger granularity. In addition, moving between black box and glass box inquiry is reminiscent of the distinction between the experimental (instance or data) space and the hypothesis (or rule) space in the scientific discovery dual search space (SDDS) paradigm described in [van Joolingen & de Jong 1996] and [Klahr & Dunbar 1988]). Finally, the ability to focus on particular aspects or phenomena (equations) within the context of a full fledged simulation environment has overlap with pedagogical methods such as problem-based learning and the jig-saw method, and we hope to elaborate on effective sequencing related issues.

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8 Appendices

8.1 The Software and Curriculum

8.1.1 Tree, Forest, and Ecology Concepts

Below we list the primary concepts, skills, and techniques addressed by the SimForest activities:

1. Tree anatomy and physiology
   - Differences between cambium and heartwood
   - Process by which trees lose their leaves
   - How trees grow.
2. Photosynthesis
   - Conceptual understanding of its processes and products.
3. Tree species characteristics and identification
   - Different species have their own sets of characteristics, requirements and range
   - Definition of the term species
   - Tree identification techniques
4. Forestry tools and techniques
   - How to measure tree trunk diameter at breast height
   - How to map a plot.
5. Forest Dynamics
   - Connections between the environment and trees: Effects of soil and climate conditions on forest composition.
   - Light competition and shade tolerance: One of the main limiting resources in a forest is light.
   - Succession: A forest goes through stages as it matures, and the composition of tree species at the beginning of a developing plot is different than the composition at the end.
   - Climax forest: Some tree species dominate a forest at the beginning and die out, while other species dominate later on and create a stable state known as a climax forest.
   - Disturbance: Disturbances can disrupt this stable state.
   - Human Impact: Human management techniques and activities have affected and continue to affect the forest of New England, and these effects differ based on the management technique or activity.
   - Randomness: Nature is not entirely predictable.
6. 7. Role and use of models in forestry and ecology

8.1.2 The SimForest Tree Growth Model

Virtually all forest growth simulation programs are in some way derivatives of the pioneering work by Botkin, Janak, and Wallis in 1972(a,b), initially called JABOWA (Dale and Shugart, 1985), which is based on the "gap phase" model of forest growth (our work is related to the more recent improved program, JABOWA II; Botkin and Nesbit & 1992; Botkin, 1993). Gap Phase models a small area (plot) of a forest (about 20 meters on a side), with the assumption that all of the trees on the plot affect all of the other trees on the plot by proximity. Tree location is not even taken into account. A tree is assumed to provide a certain amount of shade for all of the trees on the plot (which is reasonable if you consider how the shadow moves during the day). The model does not deal with the effect of the plots (or trees) surrounding a plot; it is a local model. Assuming you start with an empty plot, seeds available from the seed pool are assumed to germinate for species where the conditions are right. The model ignores the saplings until they are "breast height" (137 cm) and introduces them into the plot at this height. Then they grow and compete with each other for light. (The model does not model how trees compete for the nutrient pool -- partly because decomposing leaves and wood add to the nutrient pool). Usually a couple of large trees will dominate the plot and others will stagnate or die. When the large trees die they open up a "gap" (thus "gap phase"), where light can pour in and new seedlings will germinate.

Forest growth models continue to be an area of active scientific research, and many forest growth simulators exist (including FORET (Shugart and West, 1977), FORSKA (Prentice & Leemans 1990; Prentice et al. 1993), ZELIG (Urban, 1990; Urban et al 1991; Urban and Shugart, 1992), SIMA (Kellomäki et al, 1992, 1994; Kellomäki, 1995), SORTIE (Pacala, 1993)). These simulation models have various differences, such as the number of tree species allowed, additional environmental constraints and chemical conditions. But all are similar in that they are based on the common gap model structure (Shugart 1984). Significantly, they are geared more to professional forestry and graduate level study, and are not intended as educational tools. Our Forest Simulator software has a relatively simple forest growth model, but its interface and architecture are geared at teaching botany and ecology principles and scientific inquiry skills. Each of these programs has similar drawbacks for undergraduate research and classroom learning.

The basic structure of the growth equation in this simulation is

Main Growth Equation:

$$dD = G * D * [(Dmax - D)/D_{max}] * Lf * Tf * Wf * Sf$$

dD	=	change in trunk diameter over time
G	=	optimal growth rate
D	=	diameter
D_{max}	=	the maximum diameter (based on field observations)
Lf	=	light factor*
Tf	=	temperature factor**
Wf	=	water factor**
Sf	=	soil nutrient factor**

(G and Dmax are specific to each species, D is specific to the tree, and the other variables are determined through sub-equations.)
*Values range between 0 and 1.45, where 0 is the least favorable for growth and 1.45 is the most favorable. This value is calculated based on available light and species’ response.
**Values range between 0 and 1, where 0= least favorable conditions for growth, and 1= most favorable. These values are calculated based on site properties and species’ response.

In this equation, the increment of growth is proportional to the diameter of the tree, the growth rate, the closeness of the diameter to the maximum diameter, and the suitability of the site for that tree. This means that when at tree is significantly smaller than its maximum diameter, its growth rate increases with an increase in diameter, but as the trunk nears its maximum size the rate of growth decreases. Also, the more the suitable the site is for the tree (i.e. the closer the, water, temperature and soil nutrient factors are to 1, and the light factor to 1.5) the greater the yearly growth rate.

When you mouse-over a tree the following information shows up in the pop-up:

Site Quality (SQ) – A number between 0 and 1 that quantifies the suitability (in terms of soil nutrients, water, and temperature) of a site for that species of tree. The higher the number the more suitable the conditions. SQ = Tf * Wf * Sf.
Light Factor (LF) – A number between 0 and 1.45. It is calculated from the shading leaf weight (number and type of trees growing above the tree in question), and the light response of the species (shade tolerant, intolerant, or intermediate) The larger the number the more suitable the light conditions are for the scrolled tree.
Growth Rate (dD) - How much the tree grew this year.

There are 18 parameters for each species, that are used in various growth model equations:

> name, max age, max diameter, max height, b2, b3, g, c, light, nitrogen, DEGDmax, DEGDmin, DTmin, WLmax, maxSaplings, rgb1, rgb2, shape

Tree Growth Parameters

Each species has a number of parameters that characterize it. As mentioned above, these properties are stored in the treedata.dat file (which you can edit). All of these parameters (like the equations) are based on limited empirical evidence, theoretical assumptions, approximations, and simplifications, as used by Botkin's gap phase model (except in cases where we tweaked things for better results).

- **maxage -** The oldest possible age for the species, after which is should be dead.
- **maxdiameter** - Similar to maxage.
- **maxheight** - Similar to maxage.
- **b2 and b3** - Fitting parameters for the shape equation. The height of the tree is a quadratic function based on the diameter, with b2 being the linear term and b3 the quadratic term.
- **g** - The max growth rate for the species.
- **c** - leaf density - Describes the relation between tree diameter and "shading leaf weight" (the amount of light the tree blocks).
- **light** response - Tree's tolerance to light/shade. Has three possible values: 1=shade intolerant; 2 = intermediate; 3 = shade tolerant.
- **nitrogen** factor - Relationship between tree growth and site fertility. Has three possible values: 1=nitrogen intolerant; 2 = intermediate; 3 = nitrogen tolerant.
- **DEGDmax** - The maximum degree day value that allows for growth.
- **DEGDmin** - The minimum degree day value that allows for growth.
- **DTmin** - Describes tolerance to flooding (low value means more flood tolerance). It is the minimum distance to the water table to allow growth.
- **WLmax** - The tolerance for draught. A higher number means more draught tolerant.
- **maxSaplings** - The maximum number of saplings that can enter for that species in a year (the actual recruitment is some percentage of this, based on several factors).
- (assume min growth rate is .01 cm per year for all species)

Explanation of other Equations

Three calculations, **degree days**, **available water**, and **available light**, are a bit more arcane and are not described in detail in this document (nor are they available for inspection in either the black box or glass box forest simulators). All of the equations and parameters that the main model deals with iterate once per year. The water and degree day equations iterate over each of the 12 months, and the light equation must iterate over each tree on the plot to determine how much light it available at all possible heights from ground to canopy top. The equations that determine the available water (water table, annual water balance, water stress, and flood factor) are too complex and not relevant to botany, and are not shown. They combine rainfall, soil type, and temperature, and include calculations for snow pack, snow melt evapo-transportation, etc. The other

Some miscellaneous notes: The number 137 appears from 137 cm being where diameter is measured at "breast height." Volume is assumed to be proportional to height * diameter. Degree days = Sum[over all 365 days] (Temp – 7.2), in degrees Celsius. (Note: 7.2 is approximately (the temperature at which trees stop growing.). Lf == light factor, usu. max 1. dd == delta diam (growth rate); site quality has max of 1.

In the simulation, seed recruitment is random. Every year the simulation runs through the seed pool and allows a random number of each species to enter the plot. The minimum number of trees that can enter a plot each year is zero for all species, but the maximum number varies from species to species and is based on field observations. Once seedlings have entered the plot, their survival is determined in large part by climate, soil, and light conditions. The simulation does not display trees until they have reached breast height (4.5ft), thus if the conditions of a plot do not favor a species, their seedlings often die out before they appear on the screen.
Randomness is also built into the death function. Each year, every tree on the plot has a small probability of dying. This accounts for lightning strikes, blow-downs, animal damage and other events that might kill trees regardless of their health and vigor. If a tree's growth rate falls below .01 inches per year, its yearly probability of dying increases to 40%.
Because climate, soil, and light conditions play a large part in determining which trees will grow on a plot, two plots with the same site properties and run time will have similar compositions in terms of number, size, and species of trees. However, due to the randomness in the simulation, it is unlikely that two plots will ever be completely identical.

The black box version of SimForest contains a number of simplifications. For example, the specific location of each tree on the plot has no effect on the tree's growth rate or survival because location is not included in any of the equations . The simulated plot is only 10 meters by 10 meters, and the assumption is that any tree in this 100 m2 area has the same potential to shade or be shaded by every other tree, whether the trees are 2 or 8 meters apart. Thus, in the simulation, shading varies vertically from one layer of the plot's canopy to the next, but not horizontally within each layer. This means that in any one plot, all trees of the same height get the same amount of light whether they are directly beneath a larger tree or in an open space. Specific location is so irrelevant to the SimForest equations that the simulation even allows 2 or more tree trunks to occupy the same space. Excluding location from the equations helps to increase the simulation's efficiency without sacrificing the accuracy of the overall forest dynamics. However, the simplification does result in spatial forest layouts that do not completely mimic nature.

Other simplifications in the black box version have to do with the fact that trees in this simulation program do not affect the climate or soil characteristics. Trees cannot acidify the soil or remove nutrients and water from it. While a forest is growing, the soil maintains the same amount of water and fertility that it had before the trees grew, and when trees are removed from a plot (as in a simulated clear-cut) the nutrients stay in the soil. This situation is not true to nature. A user of the black box simulation has the ability to correct for some of the simplifications, for instance by manually lowering the fertility. Acidity is not included in the black box version at all, so there is no way for a user to manually alter this site characteristic. One advantage of the glass box version of the software is that it enables users to add equations to model nutrient loss, acidification and other factors.

Other Simplifications in the Model

> **Location:** A tree's location on the plot does not matter, only its height, diameter, age, and "leaf weight" enter into the equations. In the simulation, every tree shades or is shaded by every other tree equally regardless of their proximity to each other.
>
> **Trees and the Environment:** In this model the environment (climate, light, and soil) determine tree growth. Tree growth determines available light but has no impact on climate, water, or nutrients (i.e. roots do not increase the soil's ability to hold water, and nutrients are not lost when trees are cut.)

8.1.3 SimForest Lessons, from the "Teacher's Guide"

This Teacher's Guide consists of 3 Units. The first, Tree Trunks, Leaves and Branches, is meant to introduce students to tree biology, anatomy, physiology and identification through field and classroom work. In the second unit, Trees in the Forest students learn how to survey forest plots. The third, Forest Growth and Change, is meant to develop their abilities to use the SimForest software to investigate questions about forest dynamics.

Unit One: Tree Trunks Leaves and Branches

1. What is a Tree?
2. How Does a Tree Make Wood
3. If Wood is Made of Sugar, Why Can't We Eat It?
   Extension: What Happens to Bread in Your Mouth?
4. Other Than Air, Water, and Light, What Else Do Trees Need?
5. How Old Is a Tree's Trunk?
   Extension: If You Nail a Bird House 5 Feet Up in a Young Tree, How High Will it be in 50 Years?
6. How Much Does a Tree Grow in a Year?
   Extension: How Much Length Does a Branch Gain in a Year?
7. Why Do Trees Lose Their Leaves?
   Extension: Do Conifers Ever Lose Their Needles?
8. How Can You Tell Trees Apart?
9. Why Aren't There Leaves With Maple Shaped Leaves and Acorns?
   Extension: But What's in a Name?
   Extension: Are Trees Individuals?
10. Which Types of Trees Grow Around Here?

Unit Two: Trees in the Forest

11. How Do You Measure the Size of a Tree?
12. How Do You Map a Plot?
    Extension: What is the Soil in your Plot Like?

Unit Three: Forest Growth and Change

13. Using SimForest: Helpful Features and Information
14. How Do You Use SimForest?
15. How Does a Forest Change Over Time?
    Extension: Which Trees will Dominate the Future Canopy?
16. Does the Simulation Always Yield the Same Results?
17. Can We Simulate the Plot We Surveyed?
18. How Does Temperature Affect Forest Composition?
    Extension: How Might Other Types of Climate Change Affect Local Forests? .
19. How Do Human Made Disturbances and Management Techniques Affect Forests?
20. How Do "Natural" Disturbances Affect Forests?.
21. Is the Simulation Valid?

8.1.4 Correspondence Between Lessons and Concepts

We gave the teachers the following chart to help them match SimForest Lessons with the content that they wanted to teach.

UNIT:		Tree anatomy and physiology	Tree growth	Photosynthesis	Species characteristics	Tree identification	Trees and the environment	Forestry techniques	Site properties	Randomness	Environmental interactions	Succession	Light competition and shade tolerance	Disturbance	Human impact	The use of models in scientific research
1	What is a tree?															
	How does a tree make wood?	X	X	X												
	If wood is made of sugar why can't we eat it?	X		X												
	Other than air water and light what else do trees need?		X				X	X								
	How old is a tree's trunk?	X	X													
	How much does a tree grow in a year?	X	X				X									
	Why do trees lose their leaves?	X			X		X									
	How can you tell trees apart?	X			X	X										
	Why aren't there trees with maple leaves and acorns?	X			X	X										
	Are trees Individuals?				X	X										
	Which kind of trees grow around here?	X			X	X	X									
2	How do you measure the size of a tree?							X								
	How do you map a plot?	X			X	X	X	X	X							
3	How do you use SimForest?								X		X					
	How Does a Forest Change Over Time?		X								X	X	X			
	Does the Simulation Always Yield the Same Results?									X						X
	Can we simulate the plot we surveyed?		X		X		X			X		X	X	X	X	X
	How does temperature affect forest composition?		X		X		X		X	X	X			X	X	X
	How do human-made disturbances affect forests?		X									X	X	X	X	X
	How do "Natural" Disturbances Affect Forests?		X		X		X					X	X	X		X
	Is the Model Valid?															X

8.1.5 Sample Lessons from Teachers Guide

HOW DOES TEMPERATURE AFFECT FOREST COMPOSITION?

Goals	Driving Questions
Students will be able to **describe** the effects of temperature on a forest's ***diversity***, as it is demonstrated in SimForest. Students will be able to **design experiments** to **predict** possible effects of ***global warming*** on New England forests, using SimForest. Students will be able to **compare** and **contrast** different predictions (simulated by SimForest) of the effects of global warming.	How does the composition of a forest change with a decrease in temperature? Is there and increase or decrease in diversity? How does the composition change with an increase in temperature? Is there an increase or decrease in diversity? How might global warming affect local forests? Which New England species would be lost if the temperature rose 2 degrees, 4 degrees, 10 degrees? Does the speed of the warming matter? One concern about global warming is that the temperature will increase more quickly than the seeds of southerly species can migrate north. How could you model this using SimForest?

Teaching Tips and Background Information

The first two questions in the *other questions* list deal purely with examining the effects of temperature on forest composition and diversity and involve relatively simple manipulations of the temperature graph.

Subsequent questions become more complicated, which is fitting as they involve a complicated issue, Global Warming. The questions listed here are examples of the types of questions that could be explored using SimForest within the topic of global warming. We do not expect that any group of students would investigate all of them.

You may want to provide students with scientific literature on global warming so that they will have something on which to base their experimental design.

There are a number of ways to structure an investigation of global warming using SimForest.
For example, students could

- Begin with an empty plot and compare a plot grown in current local conditions to a plot grown in warmer conditions.
- Begin with a climax forest grown in current, local conditions, increase the temperature once, and then observe how the forest changes (and compare this to the way that the forest changes after reaching climax if the temperature does not increase).
- Begin with an empty plot, climax forest, or something in between and change the temperature a set amount on a specific time interval (i.e. increase the temperature 1^{o}C every five years).
- Change the seed pool a set amount on a specific time interval (possibly different than the temperature interval)
- Base the investigation on scientific literature.

- Choose arbitrary values on which to base their investigation.
- Compare different techniques and theories.

Students may not realize that they have all these options when they first begin their investigations. You may want to let students begin their investigations and then lead a class discussion in which students share their techniques and brainstorm different strategies with which they could explore the question of Global Warming.

Different groups could choose different theories and experimental techniques and then compare and contrast their results.

As always, encourage students to make graphs to help them interpret and communicate their data.

You may also want to assign a written report, in which students discuss their methods, sum up their predictions, identify the strengths and weaknesses of their investigations, and compare and contrast investigation techniques and predictions.

8.1.6 Contents of the SimForest Web Site

http://ddc.hampshire.edu.simforest/

SimForest Home
- About the project
- Download published papers

Overview Research
- Papers
- Funding

Professional Development Summer Institute
- SI Description
- SI photographs
- Call for participation
- Application form

Curriculum and Evaluation Materials
- SimForest Teacher's Guide
- Sample lessons and teaching tips
- Esther Shartar's "Writing an Inquiry Based Curriculum for Forest Ecology that Uses a Computer Simuation of Forest Dynamics as a Tool for Learning"
- Student Inquiry Worksheet
- Lesson Plan Template
- Daily SimForest Teacher Journal Suggestions
- Inquiry Skills Pre-Post Tests
  - Forest_fish_question.doc, Forest_flower_ques.doc, Forest_worm_question.doc
  - Pre-Post test administration instructions
- 2001 MCAS Science Frameworks [MSWord version]
- Curriculum Overview

The Software
- SimForest Description
- Software downloads
- Software Documentation
  - SimForest-B User's Guide
  - SimForest Glass Box vs Black Box
  - SimForest-G User's Guide
  - SimForest-G Equations List
  - SimForest-G Equation Editor tutorial
- Screen shots of SimForest

Related Links
- Forest Modeling
  - JABOWA
  - Modeling in Forestry - Interview With Peter Rennie
  - The Register of Ecological Models
- Inquiry-Based Learning
  - Inquiry-Based Learning at Hampshire College
  - Institute For Inquiry
- Tree Identification
  - Virginia Tech Leaf Key
  - Virginia Tech Twig Key

- UMASS Local Tree ID Hints
- MSU Tree Indentification Key

Silvicultural Resources
- USDA Silvics of North America
- UMN Silviculture Links
- About.com Silviculture Links
- Climate Change Tree Atlas

Old-Growth Forests
- Big Trees of Massachusetts
- USDA Page on Old-Growth
- Dynamics of Old-Growth Forests on Wachusett Mountain (Princeton, MA)

Tree Image Resources
- Texas A&M Vascular Plants Image Gallery
- University of Wisconsin's Index of Botanical Images

Quabbin Reservoir
- Three Views of Quabbin
- National Wildlife Federation Page on Quabbin

Contact Information
- Project Staff
- Summer Institute Participants

8.1.7 Lesson Planning Worksheet

Here is a copy of the template we provided for teachers for planning a lesson that involved the SimForest program.

<u>SimForest Project: Lesson Planning Form</u>

Teacher name: Lesson name:
Estimated lesson time: Target student audience:
Frameworks reference (version and item):

Objectives/intended learning **outcomes** (student will know ....or be able to....) A. **Content** knowledge: B. **Inquiry** Cycle Skills: <u>Learning objective</u> (Y / N)? S<u>caffolded</u> (N / Y & how?) (0. Observation skills) 1. Question/Hypothesis generation 2. Planning/designing investigation 3. Collect data/perform experiment 4. Data analysis 5. Concluding 6. Reporting/Presenting (7. Reflecting) C. Other process skills (e.g. creativity, cooperation, self-monitoring)
Prerequisite (or assumed) knowledge, skills, experiences, or lessons:
Materials needed:
Class **management**, group structure and instructional strategy notes/tips:

SimForest Project: Lesson Planning Form (page 2):

How to present the activity/task (including **introducing/motivating** it):
Rubrics, procedures, data **forms**, etc. to scaffold/structure students (attach if appropriate):
What will **students produce** or create as an output?
How will you **assess** learning:
Miscellaneous **notes**:

8.1.8 Student Inquiry Worksheet

Below is a worksheet we devised to scaffold student inquiry work in the middle school classes. Teachers modified this worksheet to fit the need of their class. The worksheet below has had the formatting changed to conserve space--the original one was two pages large had lots of space for students to enter their work.

Student Worksheet For Inquiry Learning Cycle and Reflection	Name: Date: Class & Section:
1. Restatement of teacher assigned exploration (What has the teacher asked you to investigate?) OR Individually determined exploration (What have you decided to investigate and why?)	
2. Stated Hypothesis or Prediction (What do you think you will find out?)	
3A. What is your plan? What are you going to do? List each step.	
3B. What data (information) will you collect and how will you collect it?	
4A. What did you conclude after you completed your investigation?	
4B. What evidence or reasons do you have for this conclusion?	
5. Reflection: is talking or thinking about what you have done. Now talk to some of your classmates about your findings. You may change any or add information to any of the above Give detailed explanations after talking to your classmates if you want. Was it useful talking to your classmates about your investigation and conclusions? Why?	
6. How and to whom are you going to present you findings?	

8.2 College Classroom Pedagogy Studies

8.2.1 Classroom video tape analysis rubric

Teacher and Student Moves	**Session Properties**
Teacher Questions: O (open); C (closed); L (leading); R (rhetorical) **Teacher Lectures**: M (motivating); C (content); S (summary); E (example); A (analogy); T (assigns a task)	**Locus of Information**: S->T student to teacher T->S teacher to student S->S student to student S->C student controls computer (TG) (with teacher guiding)
Student: U (software usability question); M (subject matter question); P (student performs task)	**Inquiry Cycle Steps**: Q - question, predict, or hypothesize P - plan A - analyze or model C - conclude/communicate

8.2.2 Session Activity Episodes

Trail 2B:

- Class: intro to botany (Q: what effects tree growth?)
- Sim: set properties to local conditions (w/ local weather table **hand-out**); grow.
- Class: white pines seen? (not many)
- Sim: can you get white pines to grow?
- Class: we have general agreement
- Sim: all start with same condition exactly. Grow.
- Class: are there difference? stochastic…
- Sim: systematic **collaborative** data collection
- Class: discussion of findings.

Trail 3C:

- Class: discussion of field trip
- Sim: Launch and play with site properties; until they see species from outside.
- Class: (task too difficult, regroup)
- Sim: "how long does it take to generate a white pine forest from an open field?"
- Class: How long; how big?
- Sim: try same with yellow birches
- Class: Sim did not behave as expected by expert (had a bug).
- Sim: Clear forest; plant one species, run 100 years. Do this with recruiting ON and OFF. See what happens.
- Class: discussion of interaction of species. Ran out of time.

Trail 4A1:

- Class: brief overview the inquiry cycle and research project goals; ; trees discussion (energy, growth, interactions)
- Sim: run software “What do you see happening as the forest goes from 0 to 100 years old?” Showed othog and overhead. [ES "semi-open ended"]
- Class: Using pop-up text trying to see what the species are. Opportunity to introduce Summary view.
- Sim: look at summary view. compare species with each other.

- Class: differences due to randomness in the model. Intro to site props window.
- Sim: play around with the site properties
- Sim: try to grow a Northern Hardwood forest composed of sugar maple, beech and yellow birch. [(difficult so instructor gave hints)]
- class: S: Jack pine dominated then disappeared;
- I: Why do you think that happened?" s: "light?"
- Sim: One group: thin the plot and see if Jack pine comes back; . don't thin, just run longer and see if they come back. [collaborative problem solving]
- Class: one hypothesis confirmed
- (not sure if this is end)

Trail 4A2:

- Class: brief overview the inquiry cycle and research project goals; trees discussion (energy, growth, interactions)
- Sim: run software, "see what you can discover." "How do you see what type of trees these are?" "Is there a way to slow the simulation down?" [explanation focused on software, not concepts]
- Class: lead students through features one at a time. S: what would it look like w/o Jack pine (dominant species)? I: how to remove species form seed pool
- Sim: run sim without jack pine
- Class: pin cherry now becomes dominant.
- Sim: Pick a speceis and see how old and large you can grow it.
- Class??: Site props changed too drastically form anything to grow. I: hint on climate that favors the speci4es they chose.
- Sim: try again with new climate.
- [not sure if this is end]

Trail 4B2:

- Class: start not documented?
- SiM: try to grow a local forest (climate from Western Massachusetts) forest(The Climate of Amherst book)
- Class: Has hard time finding conditions as Model has some bugs, no white pine or hemlock; hardwoods dominated. student suggests that it may be due to not enough light. Leads to **test the hypothesis:**
- Sim: cut hardwood trees to see if white pines come in
- Class: no white pines.
- Sim: try other changes suggestions by teacher to grow white pines.
- Class: still no white pines.
- -Sim: try to make conditions worse for other species
- Class: still no white pines
- Sim: remove hardwoods form seed pool.,
- Class: created white pine & Hemlock forest! Discussion of possible reasons.

Trail 5

- Sim: launch and play. See overhead and 3D.
- what did you notice?
- Sim: look at summary view.
- Class: "Do you see species you recognize for the field trip?"
- Sim: remove all species except for these 12. Run 50 years and compare.
- class: stochastics discussion
- Sim: change sit props to match local conditions. Run
- Class: Discussion on effect of incr. temp.
- Sim: each choose one species and see what props grow oldest and largest trees.
- Class: ??
- Sim: pose any inquiry question based on their curiosity
- Class: ran out of time.

8.3 Professional Development

8.3.1 Summer Institute Syllabus

The following is an overview of the agenda for the Summer Institute.

Summer Institute on Educational Software for Inquiry-based Science
Hampshire College
July 16-20, 2001

	Monday	Tuesday	Wednesday	Thursday	Friday
8:45-9:00	SETTLE IN &COFFEE				
9:00-9:20 check-in & reading discussion)	Introductions	Forest Ecology reading discussion	Inquiry Learning reading discussion	Assessment reading discussion	Try your lesson plans
9:20-10:45 #1 (1hr25)	Into the Woods!	SimForest Lesson #2	Intro to SimForest-G (Glass box)	Inquiry About Inquiry Learning	
10:45-11:00	(snack in the woods)	BREAK			
11-12:30 #2 (1hr30)	(The Woods Continued and Discussion)	SimForest Curriculum Resources	SimForest Graphing and analysis tasks	(...continued)	(…continued)
12:30-1:30	LUNCH				
1:30-3:00 #3 (1hr30)	Show and tell: What and how you teach	Designing Assessments	Massachusetts Science Frameworks	Design Your Lesson Plans #2	Revising Lesson Plans
3:00-3:15	BREAK				
3:15-4:40 #4 (1hr25)	SimForest Software #1: Intro	(…continued)	Design Your Lesson Plans #1	(…continued)	Preparation for Fall and Spring
4:40-5:00	Reflection, Feedback, Journal				

5:00-6:00 Staff meeting.

8.3.2 Contents "A Guide For Running PD Workshops for Inquiry-based Software Instruction"

Below we list the contents of the "How-To" Guide For Running a PD Workshop, from A. Galton's "Professional Development for Inquiry-Based Educational Software":

Pre Summer Institute
- Outreach and Advertisement
- Selecting Teachers In Pairs
- Solicit Support from Administration
- Computer Availability Is a Definite Pre-Requisite
- Choose Enough Teachers Familiar and Comfortable With Inquiry
- Sign A Written Contract

Design Of The Summer Institute
- Balancing Practical And Theoretical Information/Practice What You Preach
- Logistics Are Important
- Establish Daily Routine
- Receive Organized and Continuous Feedback
- Leave Ample Time For Teachers To Design Lesson Plans
- Treat The Teachers As The Experts
- Hand Out New Materials
- Invite Experts or Guest Speakers
- Plan For Celebrations

During Summer Institute
- Get To Know Each Other
- Give Teachers An Introductory Questionnaire
- Get Feedback, Continually Restructure Schedule
- Copy Resources To Share
- Designate Buddies, Create Email Network For Staying In Touch
- Set Clear Goals, Dates For Future Meetings

Immediately After Institute
- Stay In Touch
- Re-contact School Administration
- Provide Monetary And Professional Incentive

Classroom Technological support
- Give Program To Teachers On A CD
- Check That Program Runs On School's Network
- Sign Up For Computer Lab

Curricular/Teaching support
- Wait for Appropriate Unit
- Ask Teachers To Keep Journals
- Pay Classroom Visits—Offer Expertise
- Administer Student Tests For Assessment
- Be Flexible

Follow-up meetings with teachers
- Continue One Day Meetings Throughout Year
- Continue To Foster Sense Of Community
- Share Classroom Experiences and Ideas
- At The First Meeting: Encourage Teachers Who Have Not Implemented The Program To Do So
- Brainstorm Ways To Overcome Problems; Technological and Otherwise
- Schedule Next Follow-Up Meeting

Planning For Long Term Sustainability
- Review And Revise Software And Curricula
- Share Knowledge—Look For Venues To Teach Others

8.3.3 Summer Institute Daily Workshop Evaluation

The following questionnaire was given at least once a day, after several of the sessions.

1. What areas or related areas would you have liked to cover more/spend more time on?

2. What are your concerns about using what you have seen in this session in your class(es) and school?)

3. What suggestions would you make to improve this presentation/activity/session?

4. What was the most meaningful idea/suggestion/skill you gained from this session?

5. What was the most enjoyable aspect of this session?

6. As a result of this session I feel (select answer) with the inquiry model of teaching. (include comments)

   More comfortable   About the same   Less comfortable

7. As a result of this session I feel (select answer) with integrating the SimForest model into an activity in my classroom(s). (include comments)

   More comfortable   About the same   Less comfortable

8.3.4 Summer Institute Post-Evaluation Results

Below is a summary of the data from a questionnaire given to Summer Institute participants at the end of the institute, for the purposes of evaluating the success and quality of the institute. The questions were Likert-scale from 1 (strongly disagree) to 5 (strongly agree).

The number in parenthesis with an x before it indicates how many teachers gave that rating. For example for question 1 one teacher gave e 3 rating, two gave a 4 rating, and five gave a 5 rating.

1. I **met my objectives** for attending the Institute this week.
   1 2 3 (x1) 4 (x2) 5 (x5) Ave: 4.5

2. It was beneficial to share and **learn from my colleagues**.
   1 2 3(x2) 4 (x1) 5 (x5) Ave: 4.4

3. I **would recommend** this type of professional development to others.
   1 2 3(x1) 4 (x2) 5 (x5) Ave: 4.5

4. The **topics** covered in the workshop were **appropriate** and useful to me.
   1 2 3 4 (x5) 5 (x3) Ave: 4.4

5. The computer **software was easy** to use.
   1 2 (2.5x1) 3 (x2) 4 (x4) 5 (x1) Ave: 3.7

6. The workshop **materials** (handouts, articles, software) were useful.
   1 2 3 4 (x3) 5 (x4) Ave: 4.0

7. The **presentations** were clear and easy to follow.
   1 2 3 4 (x4) 5 (x3) Ave: 4.4

8. The **facilities** and arrangements were good (directions, food, location, etc.).
   1 2 3 4 (x1) 5 (x7) Ave: 4.9

9. I had **enough time** for reflection and question asking.
   1 2 3 4 (x1) 5 (x7) Ave: 4.9

10. What would you like in the way of support for preparing your classes using the SimForest software? [Answers included the following:]

- Access to having questions answered when necessary, vie web etc.
- I guess I'd like a list of some of the factors that affect tree growth with an explanation of how/why they affect the trees in plain English (no math). Web bulletin board.
- I'm OK— ** and I will support each other.
- I need an knowledgeable person to come to Chicopee to help me ID trees at our school.
- I would like to be able to contact someone with regard to program operation or finding relative to SimForest investigations.
- Knowing that 1. It's OK to call for help 2. "You" could come to our location 3. Copies of the software—in CD format.
- A telephone number to call/email address when I have questions. Thanks!

8.3.5 Ongoing Teacher Attitude Questionnaire

The following evaluation instrument was given to teachers four times over the course of their project experience: pre institute, post-institute, after semester 1 and after semester 2. Column C was added only after they started teaching.

	A. Comfort & confidence 1. high 2. good 3. moderate 4. low 5. poor	B. Understanding & Skill level 1. high 2. good 3. medium 4. low 5. poor	C. Use & adoption in your classes 1. very successful 2. moderately successful 3. sometimes successful 4. usually not successful 5. rarely successful
1. Teaching scientific **inquiry** skills (in general)			
2. Using simulation-based **software** in my classes (in general)			
3. Teaching **botany** and ecology content related to your classes			
4. Designing and using student **assessments** in your classes.			
5. Using **SimForest** software in my classes			
6. Using or adapting SimForest **curriculum** for my classes			

Comments or explanations of on any of the above choices:
(Indicate row number and column letter for each comment)

Additional questions:

What do you see as the biggest **obstacles in using inquiry learning** in your classroom?

What do you see as the biggest **obstacles in using SimForest** software and curriculum in your classroom?

What are the **advantages and disadvantages** of using inquiry methods in your classroom?

What factors having to do with logistics, research, student needs, and your needs determine **what** things **will become part of your curriculum** in general (all classes).

How helpful have **connections with fellow** SimForest Institute **teachers** been in your comfort, understanding, and use of the SimForest software and curriculum?

8.3.6 Classroom Observation Guidelines

Below is the rubric we developed for observing the secondary school classes. This rubric turned out to be a bit cumbersome, and was used informally and not completely after the first couple of observations.

Write down any relevant quotes from teacher or students, and make sure to note interactions between teachers and students.

How do software use and lesson plan, worksheet, and teacher, each promote inquiry?
Evidence for various inquiry stages and cycles:

STUDENTS were: (check off one or somewhere in the continuum)

1 2 3 4 5

engaged/excited/energetic.................passive/bored
understood task/on top of it ....confused/chaotic;
asked many questions...................asked few questions

Other attributes: patient; quiet; lacked prerequisite knowledge?
Draw "sociogram" seating and class layout diagram.
What kinds of questions do they ask? When do you notice "WHAT IFs" and "WHYs?"

TEACHER was:

1 2 3 4 5

Supportive: very.....…......not
Confident: very.........….not
Organized: very....….......not
Good at re-planning/adjusting............not good at shifting to meet changing needs
Directive (telling students information what to do).......... non-directive (letting students figure it out or decide what to do)

ENVIRONMENT:
Number of students ________ boys ______ girls _______; time length________
Uncontrollable aspects of this class that could have influenced outcome: temperature, interruptions; physical space, time limitations.

LESSON: What is the structure of the class: lecture, discussion, software, etc.. What are the main topics; main tasks and questions given to the students? What inquiry skills do they need to apply; which do they apply? To what degree are they doing things similar to Esther's curriculum? What percent of the time is devoted to inquiry activities? How many inquiry cycles?

SOFTWARE: How was software used to support inquiry? Did they understand it? How well does it support inquiry? What softwar3e features were used?

WORKSHEETS: Do kids understand how to use the worksheet? Does it help them or slow them down? Does it scaffold the inquiry? How do teachers introduce and lead use of the worksheet? What types of help do students need? Help/hints teacher offers?
Observations while doing worksheets: Look out for: What is going on that won't be found in the student answers to the questions. Any notes on the context that will avoid the worksheets being misleading is important.

Teacher **POST-INTERVIEW** (within a couple weeks) or journal:
Why did teachers think things went well or not?
Look at What factors teachers mention in describing or evaluating student leaning. How they talk about

their students as learners. What is most important to them (values; assumptions;). We may also want to get info about other inquiry lessons they teach. How long does the inquiry cycle take?

SHORTHAND

Inquiry parts:

T: Task/context/assignment
H: Hypothesis or prediction
P: Plan (include what data to collect and how)
E: [experiment/Data gathering--not explicitly in student worksheet]
C: Conclusion (with evidence/reasons)
R: Reflection
Pres: Presentation of findings

T==teacher; S==student

8.3.7 Daily Reflective Journal Instructions

Below is a copy of the template for what was suggested for the teachers to think about when doing a journal response after each lesson involving SimForest.

Please journal for 20 minutes after each SimForest class (preferably on the same day you teach). Use the questions below to inspire your writing (all of these questions are suggestions and therefore optional).
Suggested questions:

1. What was the plan? How did it turn out (mention strong and weak points)?
2. Why do you think strong and weak points were strong and weak?
3. Do you have suggestions for improvements if you were to do this lesson again?
4. Were there notable student reactions?
5. What were some personal lessons learned?
6. What did you notice related to teaching or learning inquiry skills?
7. Note aspects of the simulation software that worked well or could use improvement.
8. Any other thoughts...?

8.3.8 Teacher Periodic Interview Rubric

[The interview was done 3 times over the course of the project.]

FIRST: interviewer should read questionnaire results and clarify and probe around those.

How did SimForest classes compare with other inquiry classes you have taught?
More/less: engaging; student independent work; student-driven; time on task; time on inquiry tasks; time in lecture; number of student questions;

How is the support of this program helping (or not) your SimForest adoption.

How does your level of comfort and knowledge with the botany and ecology content effect your comfort and success in adopting the SimForest curriculum?

Describe your general teaching philosophy and behavior relate to what drives class discussion and activities; letting student questions and interests vs. the planned lesson.

Why (or when) do you decide to use the following classroom management modes: pairs, groups, individuals, class discussion, lecture.

What methods of assessment do you generally use, and what do you assess? (Content, process skills, end product, interim progress, etc.)

What factors are most influential in determining how you will present a topic to your class?

8.4 Inquiry Skills Evaluation

8.4.1 Inquiry Skill Evaluation Instrument

Below are the three instruments assigned to student subjects to test inquiry skill changes. The three tests (scenarios called "Fish," "Flowers" and "Worms") have parallel structure. A situation is described, ending with a question. Part A asks the student to state a hypothesis. Part B asks the student to describe an experiment for testing the hypothesis. Part C says "Explain why your experiment is a good way to test your prediction." Part D says "Imagine that you predicted what would happen correctly. You decide to make a graph of your data. On the graph below put some made-up data that agree with your prediction." Part E says "Now, imagine that you repeated your experiment but got different results. You used good materials and recorded your data correctly both times. Give reasons for how that could happen." Part F describes an experiment done by someone else, with a table showing how two variables were manipulated in six experimental trials. The experimental design shown in the table is flawed because both of the independent variables are changed in each trial. The instructions say "You think there is a problem with their experiment. Explain the problem and how you would fix it."

8.4.1.1 The Question of Worms and Water

Directions: Write an answer to every question. Even if you are not sure, write down what you are thinking.

The Situation: You are a biologist. You know that earthworms help plants grow. You want to help farmers have lots of earthworms in their fields. You think that the amount of water in the soil has something to do with the number of worms. You decide to do an experiment to find out more.

In the questions below you write The Story of Your Experiment:

A. To begin, write a simple prediction about how different amounts of water change the number of worms. You can make any prediction you want to. Just make sure it is clear.

B. Now you have to do an experiment to test your prediction. You can get any equipment you might need. For example, you have a greenhouse, and boxes that you can fill with soil and put worms into. Describe the experiment you will do to test your prediction. Describe your experiment step by step, so that someone else could follow the steps, like a recipe in a cook book.

C. Explain why your experiment is a good way to test your prediction.

D. Imagine that you predicted what would happen correctly. You decide to make a graph of your data. On the graph below put some made-up data that agree with your prediction. Show amounts of water and numbers of worms.

E. Now, imagine that you repeated your experiment but got different results. You used good materials and recorded your data correctly both times. Give reasons for how that could happen.

F. You meet some other biologists who are also interested in helping worms grow. They think that the amount of clay in the soil makes a difference. They show you the results of their experiment, in the table below:

Amount Of Water (Liters)	**Amount of Clay** (Kilograms)	**Number of Worms**
2	1	20
4	5	40
6	9	60
8	13	80
10	17	40
12	21	10

You think there is a problem with their experiment. Explain the problem and how you would fix it.

8.4.1.2 Fresher Flowers

Directions: Write an answer to every question. Even if you are not sure, write down what you are thinking.

The Situation: You are a biologist. You have friends who own a flower shop. They heard that adding some aspirin to the water in the vase helps keep cut flowers from wilting. They are not sure this is true. If it is true, they are not sure how much aspirin to add. They ask you to help them figure out what to do. You decide to do an experiment to find out how adding aspirin to the vase changes how many days the flowers stay fresh.

In the questions below you write The Story of Your Experiment:

A. To begin, write a simple prediction about how different amounts of aspirin change how many days the flowers stay fresh. You can make any prediction you want to. Just make sure it is clear.

B. Now you have to do an experiment to test your prediction. You can get any equipment you might need. For example, you can get lots of vases, and aspirin, and flowers you can cut. Describe the experiment you will do to test your prediction. Describe your experiment step by step, so that someone else could follow the steps, like a recipe in a cook book.

C. Explain why your experiment is a good way to test your prediction.

D. Imagine that you predicted what would happen correctly. You decide to make a graph of your data. On the graph below put some made-up data that agree with your prediction. Show amounts of aspirin and number of days flowers stay fresh.

E. Now, imagine that you repeated your experiment but got different results. You used good materials and recorded your data correctly both times. Give reasons for how that could happen.

F. You meet some other biologists who are also interested in helping keep flowers fresh. They think that the temperature of the air makes a difference. They show you the results of their experiment, in the table below:

Amount Of Aspirin (grams)	**Temperature** (degrees F)	**Days the Flowers are fresh**
20	50	1
40	55	2
60	60	3
80	65	4
100	70	2
120	75	1

You think there is a problem with their experiment. Explain the problem and how you would fix it.

8.4.1.3 Food for Fish

Directions: Write an answer to every question. Even if you are not sure, write down what you are thinking.

The Situation: Fish farmers grow fish in ponds or large tanks. You are a biologist who helps the fish farmers to grow big fish. The farmers ask you to help them decide whether adding cabbage to the fish food produces bigger fish. They don't know how much to add. They don't even know if they should add any at all. You decide to do an experiment to find out how much cabbage to add to the food to make the biggest fish.

In the questions below you write The Story of Your Experiment:

A. To begin, write a simple prediction about how different amounts of cabbage in the food changes the size of the fish. You can make any prediction you want to. Just make sure it is clear.

B. Now you have to do an experiment to test your prediction. You can get any equipment you might need. For example, you can get lots of tanks, and fish, and food, so you can try different diets. Describe the experiment you will do to test your prediction. Describe your experiment step by step, so that someone else could follow the steps, like a recipe in a cook book.

C. Explain why your experiment is a good way to test your prediction.

D. Imagine that you predicted what would happen correctly. You decide to make a graph of your data. On the graph below put some made-up data that agree with your prediction. Show amounts of cabbage concentrate and fish size.

E. Now, imagine that you repeated your experiment but got different results. You used good materials and recorded your data correctly both times. Give reasons for how that could happen.

F. You meet some other biologists who are also interested in helping fish grow. They think that the temperature of the water makes a difference. They show you the results of their experiment, in the table below:

Amount Of Cabbage (grams)	**Temperature** (degrees F)	**Weight of Fish** (kilograms)
200	55	2
400	60	4
600	65	6
800	70	8
1000	75	4
1200	80	1

You think there is a problem with their experiment. Explain the problem and how you would fix it.

8.4.2 Inquiry Skills Evaluation Rubric

Each question (A-F) has a set of desirable attributes. Score 1 or 0 (Y or N) according to whether that attribute exists. Optional: you may add "?" if you are "very unsure" about your score. You may add "!" if the subject shows an especially high degree of sophistication for that item. In general we are looking for explicit evidence of a skill, not guessing about subject understanding from implicit information.

This is a coding rubric. We will devise a scoring rubric later, that adds the items up in a weighted fashion.

Does this test have any answers that are particularly interesting or good examples that we may want to use for anecdotal description in our report? If so, what questions? (Eg. A, E). ___________

A. Write a simple prediction

1. Answer is a hypothesis or prediction. (Not a procedure, description, explanation, etc.)
2. Describes a general relationship (Not one (or a finite number of) data points or cases).
3. Includes two (reasonable) variables as specified by the description
4. Is clear about which is independent and dependent variables.
5. Relationship has a defined direction. (OK: "more" and "less"; BAD: "will help" or "more or less").
6. Hypothesis/prediction is testable or measurable.

ALSO NOTE:

7. Has a non-linear relationship (E.G. makes it bigger but too much will have reverse effect).
8. Includes a mechanism or explanation.

B. Describe the Experiment

1. Measures the dependent variable.
2. Dependent variable is specific and quantitative (measure how often; how many fish?).
3. Explicitly controls for (holds constant) at least one other external variable (other than independent variable). (not including exper. processes procedure; ex; every day you measure"). Does include holding constant initial level of dependent variable ("start with fish of the same size")
4. Systematic variation of the independent variable.
5. Is feasible to do.
6. Random or uncontrolled variation taken into account (10 vs. one fish in each tank). (includes replication or averaging over non-unit sample size)

C. Explain why the experiment is a good way to test your prediction

1. Mentions varying independent variable while holding other things constant, OR doing a controlled experiment, OR varying independent variable systematically.
2. Mentions accounting for random or uncontrolled variation.
3. Mentions consistency, repeatability, or fairness.

D. Make a graph

1. Graph correctly labeled with independent and dependent variables according to either the problem statement or their prediction in A
2. Graph has values on the axes.
3. Graph accurately corresponds to their prediction in part A.

Also note:

4. Is dependent variable is on y axis?
5. Graph type: Bar ___ Line ______ Series _______ Other (specify)

E. Reasons for another test yielding different results

1. Mentions an unaccounted for variable.
2. Mentions. human error in carrying out (not designing) the procedure.
3. (Mentions random or uncontrolled variation.--ignore for now)
4. Mentions normal measuring accuracy or variation.

ALSO NOTE:

5. Unaccounted for variables that were mentioned:

F-A. What is the problem with the two-variable experimental table?

1. Mentions both variables varied simultaneously OR that you can't tell the effect of each variable.

F-B. How to fix the problem with the experimental table?
(Skip this if F-A is 'wrong').

2. Holds one variable constant (for either one dimensional two dimensional experiment)
3. Varies both systematically as in a two-dimensional table (i.e. a factorial experiment).

8.5 Other Appendices

8.5.1 Pictures

8.5.2 Publications and Presentations

Galton, A., Murray, T. Shartar, E. Stillings, N. & Winship, L. (2002). "Sustainable Adoption of Innovative Curricula: A Case Study of Teacher Training and Support for Implementation of Educational Software in Forest Ecology." Presented at Pathways to Change conference, April, 2002, Arlington, VA.

Galton, A. (2002). "Professional Development For Inquiry-Based Educational Software." Hampshire College thesis paper.

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8.5.3 Project Personnel

Principle Investigators:

- Thomas J. Murray; Principal Investigator
- Neil A. Stillings ; CoPrincipal Investigator
- Lawrence J. Winship; CoPrincipal Investigator

Consultants:

- Laura Wenk Consultant on professional development , classroom implementation, and evaluation. Assisted daily during Summer Institute.

- Paul Zachos (Consultant on evaluating inquiry skills, session leader at Summer Institute.).
- Peter Shaughnessy (Graduate Research Assistant, professional "master" level science instructor, curriculum advisor.)

Undergraduate student interns and assistants:
- Esther Shartar (research assistant, curriculum development and testing)
- Ayala Galton (research assistant, outreach and classroom evaluation assistance)
- Steve Lester (research assistant, model verification, web site design)
- Jesse Doane (research assistant, Excel programming)
- Emmanuel Allierty (research assistant, Excel programming and design)
- Aaron Olson (research assistant, software testing)
- Samantha Stoller (software evaluation data collection and analysis)
- Ryan Lynch (software evaluation data collection and analysis)
- Gray Gauthier (prototype mock up and mock up of on-line filed guide)
- Ben Moore (Prototype mock up of Simulation screens)

Professional technical staff
- Ryan Moore- Professional programmer; Director programmer for SimForest-B
- Roger Bellin - professional programmer, Java Programmer for SimForest-G
- David Gosselin (professional, web site design)

Middle School Teachers:
- Cynthia Gould (science teacher, Leominster, grade 7)
- Pam Novak (science teacher, Glenbrook Middle School, Longmeadow, graded 7, 8)
- Patricia Tarnauskas (science teacher, Glenbrook Middle School, Longmeadow, grades 7, 8)
- Susan Pease (technology teacher, Fairview Veterans Memorial Middle School, Chicopee, grade 8)
- Deirdre Scott (science teacher, Fairview Veterans Memorial Middle School, Chicopee, grade 8)
- Karen Cousland (technology teacher, Turners Falls High, grades 9-12)
- Peter Shaughnessy (chemistry teacher, Northampton High, grades 9-12)
- Jeff Weston (science teacher, Amherst Middle School, grade 8)