Evaluation of the SimForest Inquiry Learning Environment: Inquiry Cycles and Collaborative Teaching Practices

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Abstract: SimForest is a simulation-based learning environment in the domain of forest ecology that simulates tree and forest growth and the effects of environmental and man made disturbances. The project consisted of three main stages of approximately one year each: software development, curriculum development, and classroom implementation. We evaluated the SimForest software in clinical and college classroom settings, then ran a professional development program to support eight secondary school teachers in incorporating the software and curriculum into their classes. This paper focuses on our results from the collage classroom and clinical trials. We report on a) our methods and results for measuring inquiry cycles, and b) our analysis of classroom management strategies used by an expert teacher.

Introduction

Progressive educational theories stress the importance of student-active learning and inquiry-based science education (McNeal & D'Avanzo, 1996; National Research Council, 1996; AAAS, 1993). The 'classic' scientific inquiry learning cycle can be described as including these steps/skills: posing good questions and hypotheses, planning how to answer the question or test the hypothesis, observing and gathering information, systematically analyzing information, and communicating one's conclusions, which inevitably points to more questions which starts another inquiry cycle (Tabak et al. 1996, Collins & Stevens 1993, White & Frederiksen 1986, 1995). Inquiry-based science experiences conducted in relevant, meaningful contexts have been shown to develop higher order thinking skills and more sophisticated epistemological understandings (Roth & Roychoudhury, 1993; Stillings et al. 1999, 200; Smith et al. 2000). Using inquiry methods to support 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'Avanzo 1996). Though usually discussed in terms of science learning, these skills are important to almost all subject areas, including the humanities (Prince & Kelley 1996).

Social constructivist theories emphasize the importance of collaborative knowledge building, and inquiry learning is often prescribed in collaborative learning contexts. Inquiry involves many sub-skills, each of which must be practiced with appropriate feedback in order to be mastered. For example: posing valid (clear, confirmable) questions and hypotheses, and dealing with errors, noise, and outliers in data (for a more complete list see Murray et al. 2003A). Students need to practice these skills numerous times to gain proficiency. Our simulation-based inquiry learning environment, SimForest, was designed to address these issues.

The NSF-funded 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. We evaluated the SimForest software in clinical and college classroom settings, then ran a professional development program to support eight secondary school teachers in incorporating the software and curriculum into their classes. This paper focuses on our results from the collage classroom and clinical trials. We report on a) our methods and results for measuring inquiry cycles, and b) our analysis of classroom management strategies used by an expert teacher. The first of these results is significant because, despite research and adoption of inquiry learning methods, little has been done to measure and analyze actual student inquiry cycles. The second of these results is significant because, despite numerous cases of inquiry-supporting software in classrooms, little has been done to document or prescribe teaching practices and classroom management techniques for collaborative inquiry-based problem solving using simulation environments.

SimForest

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 1, 2). 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 (the mathematical model is based on Botkin 1993). A forest plot's sensitivity to natural and man-made disturbances can be evaluated, and emergent properties such as species succession can be observed.

SimForest can be used for a wide variety of engaging learning activities, applicable to many grade levels and related subject areas. We have tested it 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. It is applicable for High School biology and ecology courses; and College ecology, botany, forestry, forest ecology, and land use planning courses. The interface itself is simple and highly usable. However, unlike many other educational simulations, there are a large number of both input parameters (initial conditions of trees and site conditions) and output properties (what can be observed or measured). This diversity provides both flexible opportunities and challenges for students and teachers. Students with an initial question such as "what are the effects of global warming?" must refine this question in terms of what parameters they will manipulate to answer their question in order to specify a clear hypothesis and experimental plan. Then they must decide which of the many output properties (number of trees, species diversity, average height, weight, or diameter of each species, etc.) they will measure.

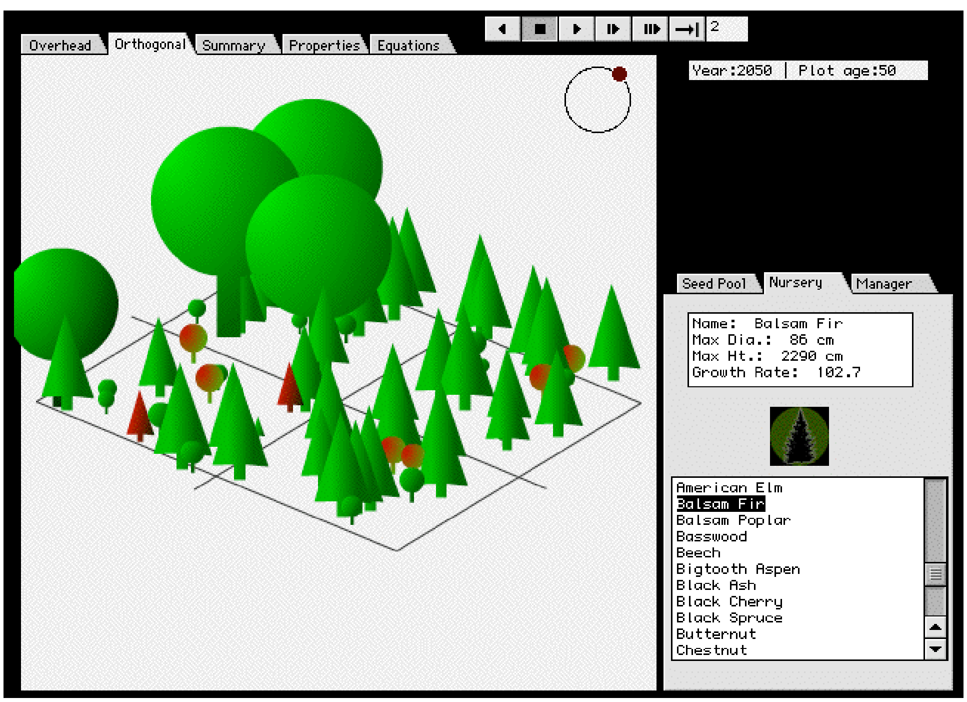

Figure 1: SimForest Main Screen

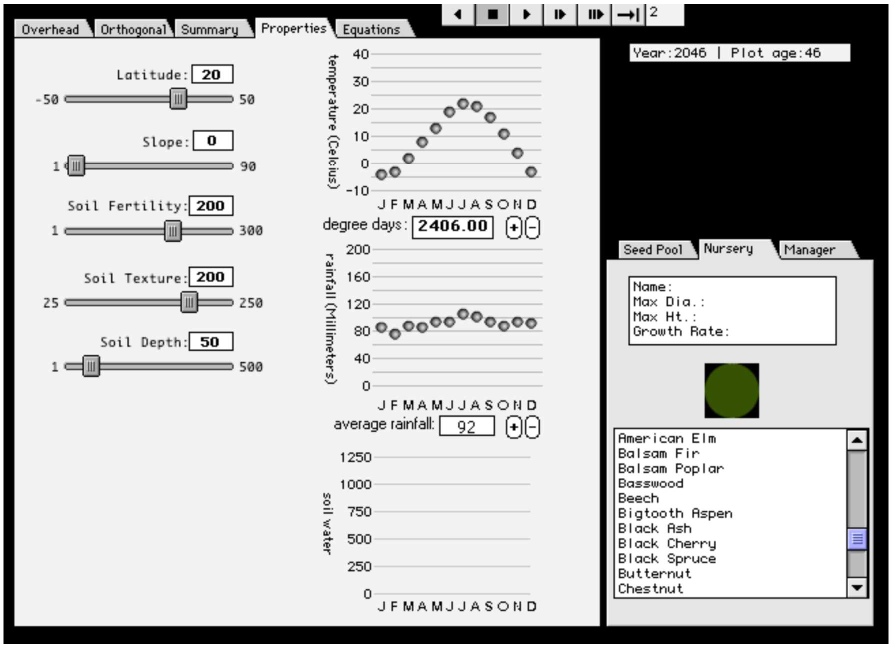

Figure 2: SimForest Site Property Window

Method

The college classroom and clinical mock-classroom sessions were lead by a botany professor who is considered an expert in inquiry-based science teaching methods, so the study was in part a case study of "best practice" performance. The professor used the SimForest software in several classes over a three year period. There were a total of 14 instructional sessions which lasted one to two hours each. In total 51 college students used SimForest in class or mock-class situations. Students worked in pairs or threes. About half of the sessions were videotaped, and observational notes were taken for all of the sessions. 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.

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 based on analysis of videotapes of four pairs of students using the software. Our transcript analysis coded for inquiry cycle phases (as described below). Figure 3 shows the rubric we used to code videotaped transcripts and to make in-class observations. The second ("global") method of measuring inquiry cycles was to analyze the flow of class activity as directed by the teacher in response to students. Specifically, we noted how many times the class cycled between small-group inquiry activities on the computer and whole class discussions. In addition, observations were made relating to the strategic teaching behavior of the instructor. The instructor dynamically 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". We observed several classroom management methods for employing distributed problem solving in the classroom.

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

Figure 3: Coding scheme used for class observation and video analysis

Measuring Inquiry Cycles

The approximately one-hour sessions were divided into naturally occurring "episodes" of varying length, averaging about 2 minutes per episode. Figure 4 shows a sample of the data. Examination of the data tables leads to the following conclusions: 1) 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. 2) 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. 3) The average inquiry cycle is approximately 10 minutes in length.

Episode->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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			
Record data																		
Verbal observations							x					x				x		
Refine Method									x				x				x	
Data analysisi	x							x										
Summarize																		

Figure 4: Sample Inquiry Behavior

At a more global level, analysis of classroom observation notes revealed how the instructor organized classes into cycles of divergent individualized work and convergent full-class discussions. The sessions lasted 1 to 1.5 hours and on the average the instructor cycled between whole class and independent work about 4 times--or every 20 minutes. The inquiry steps mentioned in the first method above occur within these larger grain-sized episodes. I.E. once the students began their independent work they usually went through several inquiry cycles (average of 10 minutes in length) before the class was brought together again. Students were able to engage in about one to 3 inquiry cycles for each larger classroom cycle. Though this data is specific to the particular simulation used and the methods used by the instructor, we can draw some tentative conclusions. We see "20 minutes" and "1 to 3 inquiry cycles" as a measure of how "far" into independent work the instructor let the students go before bringing everyone together to synthesize what was discovered and giving those who might be stuck the opportunity to ask questions in a full class context. 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 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.

Characterizing Best-Practice Class Management Pedagogy

Computer-based simulations can provide an excellent context for collaborative inquiry learning. Though many educational computer-based simulations have been developed, they are not frequently used as intended in classrooms (Blumfield et al 2000, Edleson et al. 1999, Gomez et al 2000) . The existence of the simulation is not enough, as appropriate curriculum and classroom pedagogies must be developed and used. Instructors must use skill in the selection of learning tasks and in classroom pedagogy and social management techniques. Most teachers are not sufficiently skilled in these areas, so professional development training is essential. In the case of using simulation-based learning environments used to teach inquiry skills and collaborative problem solving skills, there has been little research to identify and characterize classroom teaching strategies.

Teachers, in their attempts to develop clear activities, pose driving questions, and provide scaffolding, must make similar decisions as those mentioned above for students using the program. This is the case for many simulation-based learning situations (and most wet-lab situations as well). Our approach to dissemination and teacher training was a combination of constructivist professional development and a-la-carte curriculum materials (see Garet et al. 2001; Howe & Stubbs 1996; Simon 2000). We:

- exposed teachers to various lessons and instructional methods by demonstrating these with them taking the roles of both students and, later, teachers;
- provided activity examples and templates (these were indexed by goal topic and skill); and
- provided teaching hints and pedagogy-based explanations to help them adapt the materials and methods that we offered to their own situations.

In order to do this we first had to articulate the activities and teaching methods ourselves. The development of driving questions and activities was a brainstorming and trial and error process that came relatively directly from the nature of the simulation, the learning goals, and past teaching experience of team members. But articulating general pedagogical strategies and classroom management techniques was more difficult. As mentioned above, there is little previous research in this area for collaborative simulation-based inquiry learning. What we decided to do was to document and analyze the teaching behavior of one of our project team members, who was an acknowledged practical expert in inquiry-based and collaborative classroom methods. We later introduced these methods to other teachers who adopted them to successfully use in their own classes (see Murray et al. 2003B), but this paper focuses on the evaluation of the expert teacher's behavior. We found that the strategies that we documented from the college classroom provided relevant and critical guidance to the middle school and high school teachers, who ,of course, selected and adapted these methods to meet their individual needs.

We identified about 15 strategies or tactics used by the instructor (some are such that they can occur simultaneously). In this paper we focus on those that support collaborative problems solving. Progressive educational pedagogy views the classroom as a learning community where knowledge is co-constructed. Achieving this requires classroom management and feedback strategies that 1) engage students in tasks that they find meaningful and/or authentic; 2) engage students in separate but related tasks to allow for integrated discussion and collaborative problem solving; 3) carefully manage the divergent and convergent phases of inquiry which are long enough to allow engaged inquiry but not so long that students flounder before receiving feedback or connecting their thoughts to those of other students or groups. In our analysis of classroom management strategies, instructional styles, and feedback methods, we identified several distinct methods used to create collaborative problem solving in which the entire class was engaged in different but integrated simulation-based tasks. 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 provides a rich environment for such collaborative inquiry. Below we describe some of the methods observed and characterized (note: our "master teacher" did not plan these ahead of time, nor did he conceptualize what he was doing in terms of these strategies--they were discovered and given names through our analysis) (note that some of these strategies can be done simultaneously):

- **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.
- **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.
- **Multiple student-created tasks**. 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.
- **Unsystematic exploration**. Students were allowed to explore a parameter space unsystematically. In searching large parameter spaces randomly sampling values can help narrow down the search. Usually 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 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 while keeping the other parameters fixed at a value that, through a simulated annealing method mentioned above, was found to be close to a solution.
- **Collaborative hypothesis confirmation**. Finally, we observed several sessions in which the instructor assigned groups with conditions to test alternate hypotheses that were proposed by students in a group discussion.

We used these results to introduce teachers to possible ways to manage a simulation-based inquiry classroom in our middle school professional development program (described elsewhere.)

Conclusions

Though much has been written about inquiry, collaborative, and project-based pedagogies; and though we are increasingly seeing simulation-based technologies being used in high school and college classes, little has been done to empirically characterize collaborative inquiry-based methods in the context of simulation-based learning. Our study aims to do this from both the instructor's and the student's perspective. The analysis of both inquiry cycles and pedagogical strategies leads only to preliminary and suggestive evidence, due to the small sample sizes. However, both our methods and our results are notable because they are novel and should form the basis of further studies needed to confirm our findings.

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