T. Hirashima et al. (Eds.) (2011). Proceedings of the 19th International Conference on Computers in Education. Chiang Mai, Thailand: Asia-Pacific Society for Computers in Education

Multiple representations to support learning of complex ecological processes in simulation environments

Satabdi BASU, Gautam BISWAS
Vanderbilt University, Nashville, TN, USA.
{satabdi.basu, gautam.biswas}@vanderbilt.edu

Abstract: This paper combines Multi-Agent based simulation with causal modeling and reasoning to help students learn about ecological processes. Eighth grade students who took part in the study showed highly significant pre to post test gains on learning domain content and causal reasoning ability. Moreover, students' success in reasoning with a causal model of the ecosystem was strongly correlated with higher learning gains. This work provides the foundations for designing scaffolded multi-agent, simulation-based intelligent learning environments with modeling and reasoning tools to help students learn science topics.

Keywords: Inquiry Learning, Simulation-based Learning, Multi-Agent simulations, Scaffolding, Multiple representations, Conceptual Change

1. Introduction

Ecology has been perceived as a difficult subject because students have difficulty understanding the concepts of population and population frequencies, organization in an ecosystem, and the relationship between terms such as individuals, populations, and species [3]. This results in their using rote learning methods and linear causal reasoning, which makes it hard to reason about complex ecosystems like food webs [7].

Students' understanding of complex ecological processes can be improved by using simulations that allow them to explore and observe details of dynamic processes in the real world, which otherwise may not be readily discernible [5]. However, previous studies have shown that students face a multitude of problems with simulations linked to hypotheses generation, setting up experiments, interpreting results, and organizing them into the underlying model [4]. Thus, adequate scaffolding needs to be provided to promote learning. Multiple representations provide scaffolding by allowing users to construct, interpret, and switch between multiple perspectives of a domain [1]. Multi-Agent Based Simulations (MABMs) [8] provide multiple representations through concrete representations of biological entities and abstract, aggregate representations such as graphs that capture global temporal properties [1]. However, learning by linking the multiple representations of a MABM is not an easy task and requires appropriate scaffolding.

In this work, we introduce causal maps [6], in conjunction with a MABM simulation to help students conceptualize, model, and reason about complex ecological processes. We believe that causal reasoning is intuitive and helps students better understand concepts like interdependence and balance in an ecosystem. While a single link in a causal map represents a relation between two entities in an ecosystem (agent-level relation), reasoning in multiple-link chains of the causal map provides a global view of the ecosystem dynamics (aggregate-level relation). Scaffolds are required for mapping between the agent and aggregate level relations in a causal map, and for linking the causal map with the MABM simulation. This paper describes a Netlogo-based MABM simulation environment and the scaffolding mechanisms used to help students learn about ecosystem concepts An intervention that included 20 8^{th} grade students, produced significant pre- to post-test gains. Successful causal map building also contributed to the learning of ecological concepts.

2. Background Review

Multiple external representations (MERs) complement the advantages of one another, constrain interpretations, and provide a framework for constructing deeper understanding and insight [1]. Perceptual variability helps build abstractions about mathematical concepts and increases the likelihood of knowledge transfer [1]. However, experiments designed to study learners' benefits from MERs produced mixed results[1]. This is because learners find it difficult to integrate and coordinate representations, necessitating adequate scaffolding. MABM simulation environments like NetLogo [8] with multiple representations provide effective design scaffolds for teaching ecology concepts, especially to novices. MABMs, rather than describing relationships between properties of populations, require students to primarily focus on individuals and their interactions [8], thereby engaging in "agent-level thinking" that is intuitive for novices. In contrast, studies show that non-MABM based approaches to teach complex biological phenomena have met with limited success.

3. Methods

3.1 The simulation environment

A study was conducted with a NetLogo-based [8] MABM simulation of a Saguaran desert ecosystem. The ecosystem is modeled as a closed environment with five species: two plants (*ironwood trees* and *cacti*), their fruits (*pods*) and *seeds*, and three animals (*rats*, *doves*, and *hawks*). Each species is characterized by sets of rules that define its behavior and its interactions with other species. The simulation provides access to individual and population behaviors simultaneously, using a pictorial depiction of the inter-species interactions in the simulation window, and a set of graphs displaying aggregate populations at different points in time for each species. Learners manipulate a set of sliders to regulate the initial number of each species, and they can start, stop or regulate the speed of a simulation run at any point.

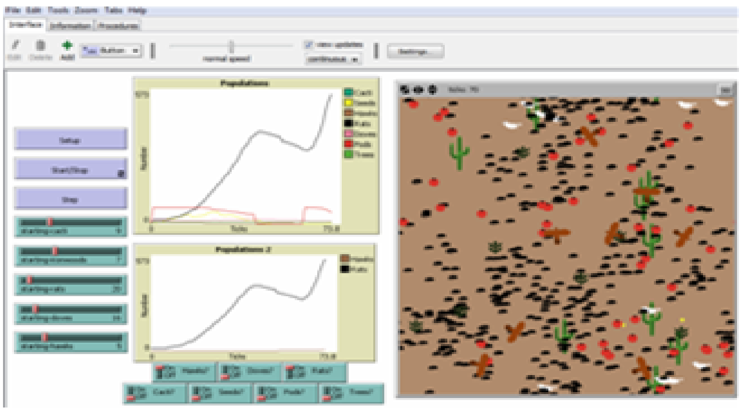

Figure 1: The user interface of the Saguaran desert ecosystem

3.2 Learning and Research Goals

Our goal was to help students infer inter-species relationships in a desert ecosystem using a MABM, and then use these relationships to build a causal model to reason about different scenarios in the ecosystem. The six relationships which students needed to infer are: (1) *Doves eat seeds of the cacti*, (2) *Rats eat seeds of the cacti*, (3) *Rats eat pods of the ironwood trees*, (4) *Hawks prey on doves*, (5) *Hawks prey on rats*, and (6) *Doves help pollinate the* *seeds*. Also, students were expected to learn about interdependence and balance in an ecosystem, pollination, the food chain, and the notion of producers and consumers.

In previous work, we studied the effectiveness of a set of scaffolds to aid learning of agent-level phenomena in ecological processes [2]. In this study, our goal was to refine the scaffolds and extend students' tasks to building and reasoning with causal maps. Specifically, the study sought to answer the following research questions: (1) Is the simulation coupled with scaffolds and multiple representations effective in bringing about deep understanding of important ecological processes? If so, is it equally effective across different achievement profiles?; (2) Does using the causal map representation to build the ecosystem model and reason causally about it help promote learning gains with respect to important ecology concepts?

3.3 Setting and Study Design

We conducted a pullout study with 20 8th graders (10 high and 10 low achievers) from an ethnically diverse public middle school in the Southeastern United States. During the study, two experimenters worked one-on-one with the students and guided them verbally as they used the simulation. Students were periodically asked to explain their answers to elucidate their incorrect conceptions and mechanistic reasoning processes. Details of the interview procedure are presented below. One of our study measures is the standard pre-to-post test gains to demonstrate the effectiveness of the intervention.

Students worked one-on-one with an experimenter for two 45 minute sessions. On Day 1, students were asked to infer the underlying model by conducting guided experiments in the simulation environment. The Day 1 intervention had three components: (1) *Introduction* – the experimenter checked the students' prior experience with simulations, and then provided an introductory tutorial on how to maneuver the UI of the simulation environment; (2) *Initial Ideas* – students were asked to execute a few simulation runs on their own, and then explain what was happening to the entities in the environment and why. These ideas were collected before any guided scaffolding was provided to help the students learn the required relationships; (3) *Scaffolded learning* – students were provided with appropriate scaffolds to help them learn about the interactions between entities in the ecosystem. At times, this involved helping students recognize incorrect conceptions before additional scaffolds were employed to guide them towards the correct relations. Students often went through multiple iterations of predicting simulation outcomes, running the simulation and explaining the results, and receiving scaffolding till they understood the relevant relations. Once students learnt a relation, they were asked to write it down to help them keep track of their own progress and findings. These notes were also used on Day 2.

The different scaffolds used are as follows: *S1. Scaffolds for setting up a simulation run* through prompts for choosing initial population parameters, regulating the speed of the simulation, deciding how long to observe, and which set of species to observe; *S2. Scaffolds for interpreting results of a simulation run* by prompting to notice the plotted graphs, relating them with the simulation window, and drawing conclusions about the interrelatedness of the species involved; *S3. Scaffolds for controlling variables and planning the construction of the underlying model of the simulation* by suggesting a vary-one-pair-at-a-time approach to study relationships between different pair of species and keeping track of which pairs have been studied and what relationships have been found; *S4. Scaffolds through self-explanations and predictions* by posing general and directed queries and asking the student to make predictions about simulation results; *S5. Scaffolding by creating cognitive conflict* by reminding students about previous contradictory findings or statements made, or by making them re-run simulations with different parameters; *S6. Scaffolding to encourage self-monitoring* by helping students keep track of their progress and previous findings; *S7. Scaffolding by providing resources* by providing detailed information about concepts which students have limited knowledge about.

On Day 2, student activities included: (1) *Model building* - students were introduced to the causal modeling tool [6], and asked to convert the relations they had noted down on Day 1 into the causal map (Figure 2). Scaffolds included reminders to model all the relationships they had noted, and capture the bidirectional nature of the food chain relationships; (2) *Reasoning about ecosystem scenarios* – Students used their model, to answer 3 questions, such as "*Imagine that a disease killed more than half the doves in the desert, how would this affect the rest of the ecosystem?*" Scaffolds provided during this phase included explaining how to reason in chains, and verifying the answers to the reasoning questions by running appropriate simulations. All the interviewer- student conversations, along with continuous videos of their on-screen actions and movements, were recorded using the Camtasia software.

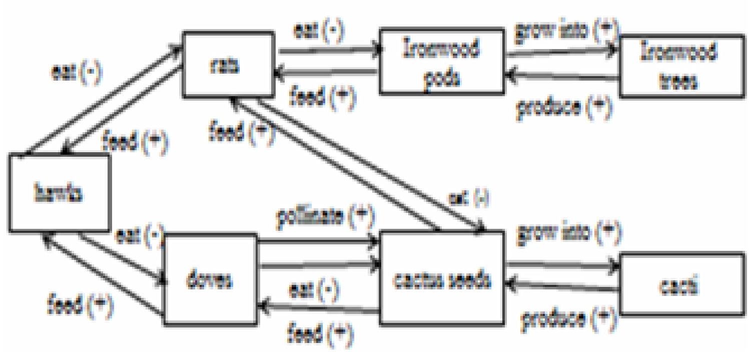

Figure 2: Causal model of the desert ecosystem

4. Results

4.1 Effectiveness of the intervention in bringing about understanding of ecology concepts

Table 2: Paired t-test results and effect sizes for pre and post test scores (n=20, df=19)

Category	Pre (S.D.)	Post (S.D.)	t-statistic	Sig (2-tailed)	Effect size
MCQ (max score=3)	0.95 (0.83)	2.40 (0.5)	8.5419	<0.0001	2.116
SQ (max score=40)	18.6 (6.10)	28.10 (4.92)	8.0214	<0.0001	1.714
CAUSAL (max score=21)	6.30 (4.38)	15.35 (5.75)	6.2414	<0.0001	1.771
TOTAL (max score=64)	25.85 (8.85)	45.85 (9.47)	8.8379	<0.0001	2.182

Table 2 presents the results of paired t-tests on the pre-to-post gains for all 3 categories (multiple choice (MCQ), short answer (SQ), and causal reasoning (CAUSAL)) of questions. The total pre to post gains were highly significant ($p<0.0001$) with high effect sizes, as were the gains for the individual categories of questions. Equally important, both high and low achievers gained significantly from the intervention, as seen in Figure 3, with the low achievers gaining at a slightly higher rate, indicating that the intervention was beneficial for both groups and helped to narrow their gaps in scores.

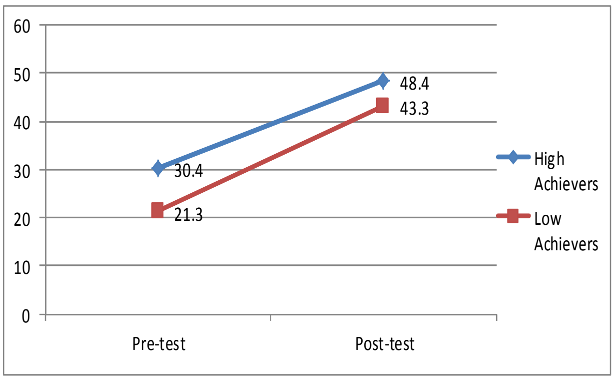

Figure 3: Pre and post test scores for high and low achievers respectively

4.2 Effectiveness of causal modeling and reasoning using another representation

Students' answers to the 3 questions asked on Day 2 were graded as a measure of their causal reasoning abilities. Students received points for identifying the correct links and for combining them correctly to generate the answer. Table 3 lists the Pearson correlations between the pre-post gains for each category of questions and these causal model reasoning scores. Since pre-post gains for some students were limited by the ceiling effect (they had high pre-test scores and could not gain much anyway), we calculated normalized gains (NGains) for each student. NGains were calculated by dividing a student's pre-post gain by the maximum amount he/she could gain depending on the pre-test scores.

Table 3: Correlations between normalized pre-post gains and causal model reasoning scores

	Pearson correlation	Sig (2-tailed)
MCQ NGain	.411	0.071
SQ NGain	.792	<0.0001
CAUSAL NGain	.712	0.0004
TOTAL NGain	.947	<0.0001

We had hypothesized that creating an explicit causal model would scaffold students' understanding of ecology concepts, and students who could reason more effectively with the causal map representation would gain a better understanding of the target concepts, thus gaining more on the post-test. True to our hypothesis, we see a highly significant ($p<0.0001$) positive correlation ($r = 0.947$) demonstrating the effectiveness of using the causal map representation in conjunction with the multi-agent based simulation environment.

5. Conclusion

The intervention described in this paper examined the benefits of using a MABM simulation in conjunction with a causal map representation and other necessary scaffolds for gaining a deep understanding of important ecology concepts. Our analysis reveals that the intervention produced significant learning gains from pre to post test for all students, and that using multiple representations effectively scaffolded this improvement. As next steps, we envision designing an intelligent learning environment with MABM simulations along with other representations and the necessary scaffolds provided by a virtual mentor agent.

References

[1] Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183-198.

[2] Basu, S., Biswas, G., & Sengupta, P. (2011). Scaffolding to Support Learning of Ecology in Simulation Environments. In Susan Bull and Gautam Biswas (Eds.), *Proceedings of The 15th International Conference on Artificial Intelligence in Education*. Auckland, New Zealand.

[3] Chi, M.T.H. & Ferrari, M. (1998). The nature of naïve explanations in natural selection. *International Journal of Science Education*, *20* (10), 1231-1256.

[4] de Jong, T. (2006). Computer simulations – Technological advances in inquiry learning. *Science 28*, *312*, 532–533.

[5] Dewey J. The pattern of inquiry. *The essential Dewey: Vol. 2. Ethics, logic, psychology*, 169-179.

[6] Leelawong, K., & Biswas, G. (2008). Designing learning by teaching agents: The Betty's Brain system. *International Journal of Artificial Intelligence in Education, 18*(3), 181-208.

[7] White, P.A. (1997, May). Naïve ecology: Causal judgments about a simple ecosystem. *The British Journal of Psychology*, *88*, 219-233.

[8] Wilensky, U. & Resiman, K. (2006). Thinking like a wolf, a sheep, or a firefly: learning biology through constructing and testing computational theories – an embodied modeling approach. *Cognition and Instruction*, *24* (2), 171-209.