A scaffolding framework to support learning in multi-agent based simulation environments

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Abstract: Simulations provide a suitable environment for discovery learning, but are not pedagogically effective unless exploration tasks are suitably scaffolded. We are developing an architecture for a computer based learning environment that includes a multi-agent based simulation, a causal modeling tool, and a set of contextualized scaffolds provided by a virtual agent to help middle school students learn important science concepts. The particular domain of study is ecosystems and ecological processes, and our goal is to help students gain a deep understanding of ecological processes.

Keywords: Inquiry Learning, Simulation-based Learning, Multi-Agent simulations, Scaffolding, Design-based Research

1. Introduction

Students' understanding of complex scientific processes can be improved by using simulation environments that allow users to explore and observe details of dynamic processes in the real world, discover the model(s) underlying the simulation, and assimilate them with their existing knowledge [4]. However, previous studies have not shown univocal outcomes that validate the effectiveness of learning through simulations [3]. When working in simulation environments, students are known to face a multitude of problems linked to hypotheses generation, setting up experiments, interpreting results, and organizing them to construct the underlying model [3]. Hence, these environments need to provide adequate support or scaffolding to students during the discovery process to promote learning. The question which naturally follows is: *What are useful scaffolds and how can they be provided most effectively?*

Multi Agent Based Models (MABMs) [9] provide multiple representations within the simulation environment and are effective scaffolds. At one level, they focus on individuals and their interactions, thereby facilitating "agent-level thinking" that is intuitive for novices. At another, students can study aggregate population models. However, this necessitates scaffolds to help them correlate the multiple representations, along with usual scaffolds for setting up experiments, running relevant simulation scenarios and interpreting results. Thus, a primary component of my research deals with designing and delivering scaffolds in MABM simulation environments to achieve more effective learning of science concepts. My domain of application is ecology, a subject that students of all ages find difficult to learn [5]. The goal is to get students to understand agent-level ecological processes (e.g., the predator-prey relations), and use this knowledge to develop a deep understanding of aggregate ecosystem concepts (e.g., food chain, interdependence, and balance).

2. Literature Review

The need for scaffolding in simulation environments has been widely recognized in the literature. Klahr and Nigam (2004) and Mayer (2004) show that offering computer simulations without support for learners during the inquiry process, often fails to foster deep

conceptual learning. Klahr and Nigam even demonstrate that direct instruction (an extreme form of scaffolding) is more productive than unguided discovery learning.
Having recognized the need for scaffolding, the focus in the field of inquiry learning is currently on how to provide the scaffolding and measure its effects. Adapting the scaffolds to students' hypotheses and experiments has been shown to be more beneficial than providing traditional predefined feedback [8].Also, the degree of scaffolding and the immediacy of feedback, have been pointed out as important scaffolding design components [2]. Quintana et al. describe a set of guidelines and strategies for scaffolding scientific inquiry learning, organized around the primary science inquiry components of sense making, process management, and articulation and reflection [6]. de Jong and Joolingen developed SIMQUEST to provide scaffolding while retaining sufficient freedom for learners to regulate their own learning processes [3]. Wilensky & Resiman showed that high school students can develop a deep understanding of population dynamics in a predator-prey ecosystem by building a MABM if they are explicitly assisted through programming support and reflection prompts by the interviewer [9]. Dickes & Sengupta showed that students as young as 4th graders can develop multi-level explanations of population-level dynamics in a predator-prey ecosystem after interacting with a MABM ecosystem when their interactions are verbally scaffolded by the interviewer [5]. For measuring the effects of scaffolds, Sherin, et al. have established a Δ-shift scaffolding framework [7] where the change in performance (ΔP) between an unassisted situation (S_{base}) and a scaffolded situation (S_{scaf}) is measured as $\Delta P = P_{scaf} - P_{base}$.

3. Proposed research work and preliminary research questions

Though several attempts have been made to develop MABM environments which provide effective scaffolding, theoretical frameworks for the analysis and systematic design of scaffolds to support students' learning of complex phenomena are incomplete. My research seeks to address this issue by developing a theoretical framework for the design, analysis, and evaluation of scaffolds to support learning of ecology in MABM simulation environments. For example, I propose to measure the effectiveness of scaffolds by extending Sherin's Δ-shift framework such that ΔP is calculated as the union of two simultaneous interdependent measures: relations learnt and incorrect relations eliminated, taking into account that these measures are inter-related.
My research will focus on designing a computer-based learning environment with a MABM simulation and a set of contextualized scaffolds provided by a virtual agent to help middle school students develop a deep conceptual understanding of important science concepts and processes. My focus is on the domain of ecology, and the intent is to help students interact with a MABM simulation to learn about deep concepts such as dynamic equilibrium in an ecosystem, interdependence between the species in the ecosystem, predator-prey dynamics, and food chains. In particular, this involves answering the following research questions:

1. *Types of scaffolds required and triggers* – (a) What types of scaffolds help students learn the models underlying ecological simulations and related ecology concepts? (b) What are the triggering conditions for each of the scaffolds?
2. *How to deliver scaffolds* - How can the scaffolds be effectively delivered by a virtual agent? What should be the dialog structure between students and the virtual agent be?
3. *Measuring effectiveness of scaffolds* – (a) What is an effective framework for measuring the effects of scaffolding? (b) How effective are the different scaffolds in producing learning gains? (c) How do students' achievement profiles and initial conceptions affect the effectiveness of scaffolds? Do they influence how the scaffolds are delivered?

Overall, I would like to systematically study the individual effects of each of the scaffolds - how the absence of one affects students' learning and the effectiveness of others. I will also study persistence of scaffolding effects in near and far transfer studies.

4. Proposed methodology and preliminary results

I have adopted a design-based approach to develop my learning environment. Currently, I have completed two iterations of this research [1]. The proposed architecture for my learning environment is shown in Figure 1. The plan is to build the system iteratively, using a design, implement, test, and refine cycle, starting from small prototypes and developing and refining the theoretical framework and the system till all the components have been implemented, and experimental studies in science classrooms demonstrate the effectiveness of the system.

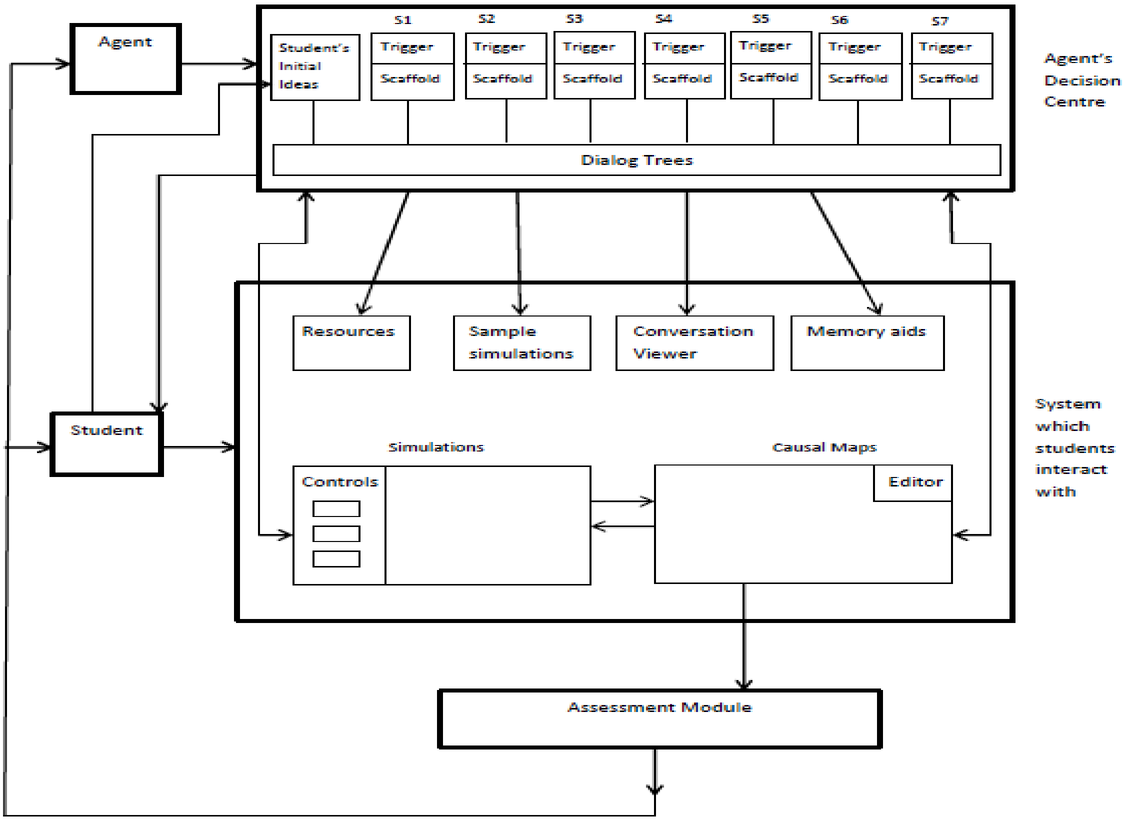

Fig 1: Proposed architecture of the simulation-based learning environment with scaffolds

The learning task in the simulation environment is scaffolded by interactions between the virtual mentor agent and the student. The agent asks specific questions to determine the students' prior domain knowledge, and then tailors the scaffolding to help students overcome their incorrect and incomplete knowledge, and progress in their learning tasks. We have identified 7 scaffolds in our initial design iterations: (S1):Scaffolds for setting up a simulation run with the correct parameters, (S2):Scaffolds for interpreting results of a simulation run, (S3):Scaffolds for controlling variables studied in a simulation experiment, (S4):Scaffolding learning using self-explanations and predictions, (S5):Scaffolding by creating cognitive conflict, (S6):Scaffolding to encourage self-monitoring, and (S7):Scaffolding by providing resources. In the first exploratory study, the scaffolds provided verbally by the interviewer were categorized post hoc as S1-S5 [1]. Though these scaffolds were highly effective [1], further scaffolding, i.e., S6 and S7 were necessary to help students gain mastery of the ecological concepts.

Along with the simulation, students are simultaneously asked to build a causal map of the ecological model underlying the simulation. The agent scaffolds students' learning of the underlying simulation model and its translation into the causal map. Some examples of additional support provided are: example expert simulation scenarios, a hypertext based resources library, the conversation log/viewer, and memory aids for helping student keep track of experiments they performed using the simulation. The agent is also designed to monitor students' interactions with the simulation controls, the simulation results and the causal maps built by the students. This information helps guide the agent's scaffolding dialogs. Finally, the environment supports dynamic assessment with a tool that allows students to periodically check the correctness and completeness of their causal map. The mentor agent uses the assessment results to further guide the student.

Results from a study with 20 8th graders to test the effectiveness of the scaffolds showed highly significant pre-to-post test gains ($p<0.0001$, effect size=2.18) . Also, students who could reason with their causal models had higher pre-post gains ($r=0.95$, $p<0.0001$). These studies have also helped identify triggering conditions for the scaffolds based on student actions and preconceptions, which will govern the dialog structures in my proposed learning environment.

Using this architecture, I propose running the following experiments in the coming year:

1. Evaluate the effectiveness of the scaffolded intervention by comparing performances using the Δ-shift framework of a control group that works in the simulation environment with no scaffolds and an experimental group that uses all the scaffolds. We may also run variations of this experiment to study the effectiveness of individual or groups of scaffolds.
2. Study the effectiveness of using the causal map representation. All students will receive scaffolds S1-S7, but the control group will not have access to the causal mapping tool.

5. Conclusion

In summary, my thesis research involves an iterative design-based-research project for building an effective learning environment using MABM simulations for deep understanding of important scientific concepts. The architecture is based on finding from my first two iterative design studies. Since my research particularly focuses on the domain of ecology, this learning environment, when implemented, will have at least two major contributions: (1) provide a learning tool for a difficult subject like ecology, and (2) demonstrate how to use MABM simulations effectively for learning.

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