GenEvo - An emergent systems microworld for model-based scientific inquiry in the context of genetics and evolution

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Abstract: In this poster, we discuss GenEvo, a learning environment that we have designed to engage students in scientific inquiry practices in the context of genetics and evolution. GenEvo belongs to a class of constructionist learning environments that we call Emergent Systems Microworlds (ESM) which combine two design approaches: agent-based modeling of emergent systems and constructionism. An increased emphasis on learning scientific inquiry practices through the use of models has created demand for model-based curricula that incorporate authentic disciplinary inquiry practices. We argue that the design of GenEvo allows students to engage with disciplinary ideas central to modern biology, as well as complex systems thinking that is crucial in contemporary biological research. We also demonstrate that GenEvo makes advanced disciplinary ideas accessible to students in two very different global research settings.

Introduction

There is a huge disparity between high school biology instruction and the research practices of modern biologists (Wilensky & Reisman, 2006). Our work seeks to address this gap by combining two powerful design approaches in learning sciences, namely, agent-based modeling of emergent systems and constructionism (Wilensky & Rand, 2015; Kafai, 2006). We call our design approach Emergent Systems Microworlds (ESM).We use this approach to make cutting-edge ideas in modern biology such as molecular genetics and genetic regulation ideas accessible to middle and high school students in different global settings (India and the United States), by engaging them in the research practices of computational modeling and complex systems thinking.

Emergent Systems Microworlds

In this paper, we are coining the term Emergent Systems Microworlds (ESM) to describe the learning environments that are designed by combining two design approaches, agent-based modeling of emergent systems and constructionism. In agent-based modeling environments, an agent is a computational object with particular properties and actions. An 'emergent' phenomenon, is modelled in terms of agents and their interactions (Wilensky & Rand, 2015). Prior research has demonstrated agent-based modeling to be a powerful approach for explaining and understanding emergent phenomena across a wide range of domains, including the natural sciences (e.g., Blikstein & Wilensky, 2004; Levy & Wilensky, 2006). In order for students to explore and learn about emergent phenomena, we use computational models that are designed in the form of a microworld. Microworlds are encapsulated open-ended computational exploratory environments in which a set of concepts can be explored, through interactions that lead to knowledge construction (Papert, 1980). In the use of a microworld, a learner is expected to manipulate the objects and execute specific operations instantiated in the microworld, in order to induce or discover their properties and the functioning of the system as a whole (Edwards, 1995). ESMs are a specifically designed to support students in creating, exploring, and sharing virtual models of dynamic systems that exhibit emergent phenomena. ESM-based curricula engage students in personally meaningful model construction and debugging processes. In addition, these curricula are also designed for students to share their constructions with their classmates and benefit from interacting with each other.

The GenEvo curriculum as an ESM-based curriculum

Our ESM-based curriculum GenEvo uses NetLogo to model emergent phenomena (Wilensky, 1999), an agent-based modeling platform which is intentionally designed to foreground emergent systems modeling for educational and research purposes (see Wilensky & Reisman, 2006). This curriculum focuses on making explicit connections between three organizational levels in biology, namely the cellular, the organismic, and the population level. Interactions between agents, like DNA and proteins at the molecular (micro) level result in an emergent phenotype at the cellular or organismic (macro) level. Competition between organisms (micro) results in the emergence of fitter traits at the population (macro) level. We have designed computational models in the form of microworlds that allow students to explore emergent systems across these three levels. Students investigate these models through a series of scaffolded, playful explorations. When students set initial conditions by changing the values of sliders and run the simulation, they observe agent level behaviors in the environment.

The computational interface also contains several plots where students can observe changes at the system level such as changes in energy of the cell over time. As students design and conduct computational experiments in the ESM learning environment, they collectively build the ideas about emergent properties in the ESM.

Research Design and Results

Given the relative novelty of ESMs and their effectiveness in supporting learners, we became interested in how these tools and curricular materials that use these tools work differently across global settings. In pursuit of this goal, we partnered with two institutions, one in the US and one in India. The data presented in this paper is from a Computational Modeling in Biology course taught at both institutions. Participating students in these programs ranged from 11 to 14 years of age and were intellectually advanced based on their academic performance. In the United States cohort, there were 14 students (6 female, 8 male) of mixed racial and ethnic backgrounds (6 White non-Hispanics, 4 Asians, 1 White Hispanic, 1 American Indian or Alaskan Native, 2 identifying as Other). In the summer residential program in India, 15 students participated (8 female, 7 male), all of Asian Indian origin. We used mixed-methods analysis to investigate whether students learned disciplinary core ideas through their participation in ESM-based curricula and how students engaged in scientific inquiry practices. In this poster we present the qualitative analysis of learning gains.

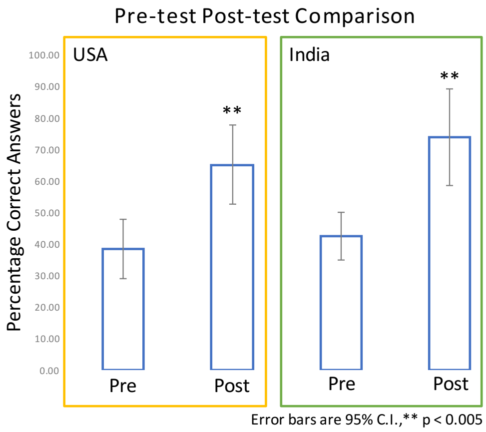

Figure 1: Pre- and post- tests comparison showing that both the courses showed significant learning gains

We performed quantitative analysis to investigate learning of disciplinary core ideas (DCIs) in Genetics and Evolution. All the students who consented to participate in the research study took both a pre- and a post-test. These tests were a series of randomly assigned multiple choice questions that tested students' understanding of the DCIs. We find significant learning gains ($p < 0.005$) comparing pre-post scores in both the US ($n = 14$) as well as in India ($n = 15$) (See Figure 1). These gains establish the effectiveness of the ESM-based GenEvo curriculum in teaching advanced biological core ideas in both the settings.

In this paper, we have discussed the design and effectiveness of GenEvo as an ESM-based constructionist curriculum. We are in process of conducting qualitative analysis to characterize student learning and participation to develop insights into how an ESM-based curriculum supports learning of scientific and complex systems thinking.

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