Running head: LEVELS OF REASONING ABOUT NATURAL SELECTION

Agent-based and aggregate level reasoning elicited by problem scenarios and an agent-based model

Abstract

Evolution by natural selection can be viewed as a complex system involving patterns at the aggregate level that emerge from interactions among local-level agents. The present research study investigates the nature of complex systems reasoning elicited by two different types of instructional materials, text-based problem scenarios and an agent-based model of natural selection. Semi-structured interviews were conducted with graduate students in the humanities and social sciences. The text-based problem scenarios and the agent-based model served as a context for the students to answer questions about natural selection. Results showed that the agent-based model elicited both agent-based reasoning and aggregate-level reasoning while the text-based scenarios mainly elicited aggregate-level reasoning.

Purpose

The purpose of this study was to investigate how novices in evolution make sense of text-based problems and an agent-based model of natural selection. In particular, their reasoning was analyzed to explore how the two kinds of instructional materials (text-based problems and an agent-based model) triggered agent-based reasoning and aggregate-level reasoning from a complex systems perspective.

Perspectives and/or theoretical framework

Traffic jams, slime mold cells clustering and gas laws all are different phenomena that have one thing in common; they are all instances of complex systems. A complex system consists of many individual elements (that are often called agents) which interact with one another and with the environment. These interactions result in higher level, collective behavior and patterns at the aggregate level (Wilensky, 1999a, 2003; Wilensky & Resnick, 1999). This aggregate level behavior resulting from interactions at the agent level is a fundamental characteristic of complex systems and is also known as emergence.

Though the behavior of individual agents is often simple to understand, the behavior of the whole system can often be complex to understand and difficult to predict (Wilensky & Reisman, 2006). Several studies show that students often have difficulty grasping emergent phenomena along various dimensions (Hmelo-Silver & Pfeffer, 2004; Jacobson, 2001; Wilensky & Resnick, 1999). For instance, Wilensky and Resnick (1999) have found that students often exhibit “levels confusion” in trying to understand complex systems. That is, they tend to attribute properties of the agents to the aggregate level or vice versa. Another pattern of thinking associated with difficulty in understanding emergent phenomena is a deterministic-centralized (DC) mindset (Resnisk & Wilensky, 1993; Wilensky & Resnick, 1995, 1999). The DC mindset implies that students incorrectly tend to assume that the pattern at the aggregate level results from the individual control of one agent or from some form of centralized control instead of from the interactions of multiple agents. Thus, students typically have difficulty understanding complex systems and the emergent nature of complex systems.

The field of biology has several instances of complex systems and has been a particularly prolific domain for research related to complex systems (Kauffman, 1995; Langton, 1994). The brain, predator-prey relationships, the behavior of ants and bees are all instances of complex systems that consist of different agents interacting with one another to result in aggregate level patterns and behavior. The complex system that is the focus of this paper and study is evolution, the study of the origin and development of species. Evolution can be viewed as an emergent phenomenon that results from the interactions among agents at different levels such as the genetic level, at the level of an individual species or the level of ecosystems consisting of several species evolving over time.

Evolution is a core topic of biology and is the primary scientific explanation for the diverse forms of life around us. It is central to understanding the underlying similarities, differences and occurrence of new forms of life in the world. The quote by the famous biologist, Theodosius Dobzhanksky highlights the importance of evolution in the domain of biology:

> "Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light, it becomes a pile of sundry facts some of which interesting or curious, but making no meaningful picture as a whole."

- Dobzhansky, 1973, ("Nothing in Biology Makes Sense Except In The Light of Evolution", Am. Biol. Teacher 25:125- 129; p.129)

Despite the importance of this topic, several studies show that a lack of understanding of evolution is common. Low levels of understanding of evolutionary mechanisms is commonly found among high school students (Clough & Wood-Robinson, 1985, Demastes, 1995), undergraduates (Bishop & Anderson, 1990), biology majors (Dagher & Boujaoude, 1997), medical students (Brumby, 1984) and science teachers (Affanato, 1986, Osif, 1997, Nehm & Schoenfeld, 2008). This lack of understanding reported by research studies is disturbing because of the importance of the topic evolution in biology and its wide applicability to other spheres such as economics, agriculture, livestock farming etc.

Previous research has shown that students' understanding of emergent phenomena like evolution can be made more robust when students engage in innovation curricular materials such as exploring agent-based models (Ioannidou, Repenning, Lewis, Cherry, & Rader, 2003; Klopfer, 2003; Levy,Kim,&Wilensky, 2004; Resnick, 1994; Wilensky, 1995, 1997a, b, 1999a; Wilensky & Reisman, 2006; Wilensky & Resnick, 1999).

This study is based on this work. Specifically, this study examines novice reasoning of an evolutionary process, natural selection from a complex systems perspective. It is a preliminary attempt at capturing how two different kinds of instructional materials, text-based problems and an agent-based model elicit agent-based, aggregate-level and emergent reasoning among novices in evolution.

Methods

Four participants who were graduate students from the field of humanities and social sciences and had little or no background in life sciences and biology after high school were interviewed. The semi-structured interview consisted of two parts which were counterbalanced across the participants to control for order effects.

In the first part, participants were presented with two text-based problems of natural selection, one at a time and were asked questions about them.

After that, they were introduced to an agent-based model of natural selection in a population of six types of bugs. This model was developed as a part of the BEAGLE curriculum (Wilensky & Novak, n.d.) using NetLogo. NetLogo (Wilensky, 1999b) is an agent-based modeling language that provides the modeler a framework to represent the smallest constituents of a system, the agents, and a way to simulate the interactions among these agents over time. NetLogo is an ideal platform to develop models for emergent processes like natural selection because it enables the user to model and observe change to individual elements or agents through time.

In the interview, participants explored an agent-based model of a population of bugs using NetLogo. They were asked to assume the role of a predator and eat bugs. Participants were given two different scenarios that involved two kinds of predatory behaviors, one in which the predator chased prey, and the other in which the predator was stationery. Following model exploration in each scenario, participants were asked to observe changes in the bug population over time and answer questions about the same. The text-based problems, NetLogo model and the explorations provided a context for the participants to reason about natural selection.

Data sources & coding

Participants' responses were transcribed and coded line-by-line for three kinds of reasoning, aggregate-level reasoning, agent-level reasoning and emergent-level reasoning. Instances of each of the codes have been provided in Table 1.

Aggregate level reasoning is instantiated in terms of group properties, populations and flows between groups (Wilensky, 1999a, 2003; Wilensky & Resnick, 1999). In the case of natural selection, a change in numbers of a certain group over time would be an instance of aggregate level reasoning. On the other hand, agent-based reasoning involves rules or conditions and actions for individual behavior. In the case of natural selection, any comment about the individual behavior of the bugs or the predator would be an instance of agent-based reasoning. The recognition that group patterns emerge from the behaviors or rules of individual agents is an instantiation of an understanding of emergent phenomenon.

	Instances for coding
Aggregate-level reasoning	"Umm, so in places where there has been a predator throughout time, the prey lizards have been naturally selected as being longer legged".
Agent-level reasoning	"The prey first reacted by sort of you know, sort of, reacted by moving to higher altitudes because that is sort of the natural thing to do because the predator was clearly, they moved to higher altitudes because you could deduce from that that predator was mainly a ground creature"
Emergent process	"Well, the current bug population, umm, you have a lot more of the purple bugs now, I mean it's the same explanation I gave before. I think that umm, as a function of speed, the purple ones are probably covering less area than the other two so they're less likely to be eaten and more likely to stick around and they're not going to bump into the prey, they're less likely to bump into the prey and as a result, I'm going to catch more of the red and orange bugs".

Table 1: Examples of coding for each of the three types of codes

Results

The results are presented below in table 2. Participants were more likely to engage in agent-based reasoning when using an agent-based model and they were more likely to engage in aggregate-level reasoning when presented with a text-based scenario. However, surprisingly, participants engaged in emergent level reasoning more often when presented a text based scenario than an agent-based model.

	Text-based scenario	Agent-based model
Aggregate-level reasoning	46.93	37.57
Agent-level reasoning	7.59	25.13
Emergent level reasoning	26.52	20.21

Table 2: Percentage of statements from student responses to the questions

Scientific or scholarly significance of the study

As highlighted by Dobzhansky's quote mentioned earlier in this paper, evolution is a core topic in the biological sciences. The importance of the topic of evolution highlights the need for educators and education researchers to ensure that students have a sound understanding of evolutionary processes.

From a complex systems perspective, a sound understanding of evolutionary processes such as natural selection would imply bottom-up understanding of the emergent nature of natural selection; that is, the recognition that aggregate level patterns in natural selection emerge from interactions among the organisms (agents) with one another and with environmental factors. However, traditional biology instruction typically separates the two levels and tends to focus on the aggregate level (Levy & Wilensky, 2008).Wilensky and Stroup (2003) have argued that both aggregate level reasoning and agent-based reasoning are crucial and necessary for a sophisticated understanding of emergent phenomena.

Research shows that emergent phenomenon are typically challenging for students to understand (Penner, 2000, 2001). In order to truly understand emergent phenomenon, students need to not only recognize macrolevel patterns and the agent-based microlevel interactions of a complex system, but also recognize that the macrolevel patterns emerge from the microlevel interactions. However, the results of this study show that participants engaged even when participants engaged in agent-based reasoning more often when using agent-based models, they displayed emergent level reasoning more frequently when presented with text based scenarios. This might be because of the small size of the sample of the study.

The authors of this paper do not perceive these finding as disappointing for two reasons. Firstly, in this study, no attempt was made to teach the participants or to provide them an environment in which they could learn about the emergent nature of natural selection. The interview was conducted with the intention of exploring the kind of reasoning that is elicited in response to the two different instructional materials based on the prior knowledge of the participants. It is likely that if the text and agent-based materials were explicitly used for teaching and learning, the results might have been different. Secondly, if agent-based models of natural selection do elicit agent-based, aggregate-level and emergent thinking, further research can be conducted to explore the kinds of scaffolds that can be provided to help students engage in bottom-up reasoning about the emergent nature of natural selection.

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