Leveling the Playing Field: Making Multi-level Evolutionary Processes Accessible through Participatory Simulations

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Abstract: Recent research in Learning Sciences has drawn attention to the affordances of enabling students to learn about scientific phenomena through a complex systems lens. In this study, we adopt a complex systems perspective in helping students learn about a multi-level phenomenon, artificial selection, by using an agent-based participatory simulation – Bird Breeder. Our goal is to investigate how design revisions to the activity in the form of 1.) Explicit representations of students' shared experiences, 2.) Access to an underlying third level of alleles, and 3.) Transparent rules of interaction facilitated abstraction of population-level trends in terms of change over time. We draw on data from two iterations of an agent-based modeling curriculum for evolution as part of a design-based research study in three tenth grade biology classes in the mid-west. The findings hold implications for the design of participatory simulations in general, and ways to support meaningful learning about complex multi-level phenomena in particular.

Literature Review

The study of complex systems is quickly becoming a new strand of literacy (e.g., Ben-Zvi Assaraf & Orion, 2005; Jacobson & Wilensky, 2006) because it offers new explanatory frameworks and methodologies that are increasingly being adopted in scientific and professional environments. We consider a complex system to be an emergent system in which population-level trends emerge from individual-level mechanisms.

Biology is replete with instances of complex systems in which phenomena can best be understood by grappling with relationships between levels in the system. Evolution, which is central to the study of biological sciences, is one such complex emergent phenomenon that involves change at multiple levels of the population such as the level of alleles, organisms and species. While most work on student learning about evolutionary processes focuses on an understanding of connections between two levels, we try to support student reasoning about a third underlying level, the level of alleles or genes of individuals in the population.

We do this work using agent-based models (ABM). In an ABM, individuals in a system are assigned rules for interaction with other individuals or the environment. The execution of these rules, over time, results in distinct, often surprising, trends at the aggregate level. This delineation renders ABMs as an epistemological match for learning about evolution for a couple of reasons. First, they provide accessible entry points for learners who have cognitive resources at the agent-level (e.g., Papert, 1980) that can be leveraged to build conceptual links between agent-level behaviors and aggregate-level trends (e.g., Wilensky & Reisman, 2006). Second, ABMs alleviate a difficulty associated with learning about evolution in particular, and complex systems in general called *slippage between levels* (Wilensky & Resnick, 1999d).

Most of the work using ABMs to learn about evolution has involved students exploring models of evolutionary processes as an *observer* of the system (e.g., Wilensky & Centola, 2007; Wagh & Wilensky, 2012a). In this paper, we examine the use of ABMs in which students are *participants* in the system. This is done using a particular form of a computer-supported collaborative learning environment called a *participatory simulation.* The experience of engaging in a participatory simulation can be characterized by Ackermann's (1996) metaphor of "diving-in" and "stepping-out" to develop a deep understanding of a system (Colella, 2000). "Diving in" entails taking the perspective of an agent in the system, by enacting the role of the agent from within the system, while "stepping-out" entails projecting and objectifying one's personal experience in order to deeply understand it (Ackermann, 1996). Going back and forth between diving into the system, and stepping out, enables learners to increasingly appropriate the relationship between emergent aggregate-level change in the system and the agent-level mechanisms that drive the change (Wilensky & Stroup, 1999a).

In this paper, we describe how students synthesize population-level trends in stepping out of a part-sim, Bird Breeders, which is part of a curriculum on evolution (Novak & Wilensky, 2010). Specifically, we examine how design revisions to the activity supported abstracting population-level outcomes of the part-sim. Prior work has described how diving into this part-sim enabled students to spontaneously adopt, and later project and objectify the mechanisms underlying the system (Wagh & Wilensky, 2012).

Bird Breeders Participatory Simulation

The Bird Breeders activity was developed in the HubNet module (Wilensky & Stroup, 1999a) of NetLogo (Wilensky, 1999b). Working in groups of four, each student assumes the role of a bird breeder and is randomly assigned three or four birds at the start of the simulation. These birds differ from each other with respect to four traits: the color of their crest, tail, breast and wings. The group's goal is to breed birds that are homozygous recessive for the four traits.

Methods

This study was conducted in the context of a two-week long implementation of an evolution curriculum as part of a design-based research study (e.g., Brown, 1992; Collins, 1990). In this paper, we report on data from two iterations of implementations each conducted in three tenth grade biology classes in a mid-western town in the United States. The same teacher led this implementation in both iterations.

Here, we specifically report on data from the Bird Breeders participatory simulation of artificial selection. In both years, the students spent one class period working on the Bird Breeders model. Note that in this paper, we focus on what students explicitly reported to have understood about the mechanisms and outcomes of selective breeding. In general, when characterizing student responses in both years, a dimension that was important to us was a description of outcomes in terms of *populations changing over time.* This is because as the first activity in a curriculum on evolution, we wanted it to foster an understanding of artificial selection as changing populations over time, so that this understanding could be leveraged through the rest of the curriculum.

Findings from Year 1

In the first year, we analyzed 18 student responses to examine student descriptions of what they had learned about outcomes of selective breeding. Though student responses varied, ten out of eighteen student responses involved static descriptions of specific birds in the part-sim (e.g., "red wings, blue feathers, grey belly") or a seemingly random response such as "3 results would be color of the fur, the ear shape, and the length of the hair". Though these responses were not "incorrect", we hypothesized that a lack of attention to how a population changes over time would make it difficult for these students to leverage their experience of having engaged in this activity to understand other evolutionary processes later in the curriculum.

Only eight out of eighteen student responses focused on a change in the bird population over time. This led us to revisit the design of the activity to reconsider some of our design decisions. We had two goals: 1.) To support more students in being able to describe the outcomes of selective breeding in terms of populations changing over time, and 2.) To encourage students to notice an underlying third level, that of alleles and genes, and examine how it was changing over time as well.

Design Revisions based on Findings from Year 1

In re-considering our design decisions, we wanted to foreground how the population had changed over time, both at the level of individual phenotypes, and the underlying gene pool. These dual goals led to three main design revisions, each of which will be described in detail here:

1. Explicit aggregate-level representations of students' shared experiences

In looking back at the design of the activity, we noticed two sources of difficulty: one, the data students collected in the activity did not help draw their attention to how the population had changed over time. For instance, groups collected data on the number of birds they had to release into the wild, and the number of eggs the group had laid. The underlying rationale for collecting this data was to facilitate a comparison of effectiveness of different strategies that groups had adopted to breed the goal birds. However, the iteration in Year 1 made it clear to us that though this goal of comparing strategies was important, it was more important to draw students' attention to changing trends in the population. Perhaps more problematically, the original Bird breeders' model did not include plot/s to track the changing population. In the absence of an aggregate-level representation to record change in population, the students did not have a reference point to step out and reflect on the outcome of their shared experiences and reason about population-level trends.

To address these issues, we decided to include plots of changing frequencies of variations (phenotypes) and alleles in the population. In addition, at the end of the activity, students were asked to record the plots, instead of number of birds and eggs. The goal was to draw their attention to how the population had changed over time.

2. Giving access to an underlying third level of alleles

One group's use of the "prohibited" View-genotype feature led us to think more carefully about the affordances of this feature. In the original version of this model, turning on the View-genotype switch made the genotype information of all birds available at once, and left it available until the feature was turned off. This unlimited access to the genotypes of all birds made the task less challenging.

We decided that a design fix would include a feature that enabled students to access the genotype of birds a fixed number of times. This led to the development of a new feature called "DNA Sequencer". With this feature, each player could pick a certain bird to sequence its DNA, and get access to the genotype of that bird for the rest of the simulation. However, each student could do this for only a fixed number of birds, determined by a slider in the simulation. Providing groups with limited access to genotypes through the DNA sequencer ensured that the challenging nature of the task was not compromised.

3. Transparent rules of interaction

Our class observations from Year 1 suggested that some groups had difficulty learning the rules for participating in the simulation. This lack of clarity often frustrated students who unintentionally released prized birds or repeatedly attempted breeding birds without success. It is perhaps because of this lack of transparency of rules that all groups did not succeed in breeding goal birds in Year 1.

In order to rectify this issue, we decided to add visual cues to the simulation to make rules for interaction transparent. First, a bird's readiness to breed is indicated by a heart that appears next to the bird. A little arrow next to the bird denotes that it needs to be taken back to its cage before it can be used for breeding again. Finally, the area in which birds can be released into the wild is represented by green grass. These visual cues were intended to make participation in the simulation smooth and effortless, so that groups could focus on the activity itself.

4. Breeding more goal birds

As previously described, this activity is atypical of participatory simulations because of its small scale. Though classic part-sims include the entire class, the Bird Breeders model included groups of four students. This small-scale might have made it difficult for students to notice population-level trends when breeding only three homozygous recessive goal birds. Hence, we revised the activity so the goal for each group would be to breed three *pairs* of goal birds, rather than three birds to make the trend more noticeable.

Findings from Year 2

In Year 2, we implemented the revised version of the Bird Breeders part-sim. Here we report data from 11 responses of 22 students working in pairs.

In the class discussion, the students decided to divide up their responses about outcomes into three categories: "Big differences between individuals at the beginning and the end", "Changes gene pool", and "Offspring with desirable traits". In developing our own categories to sort student responses, we realized that our categories very closely aligned with the ones that the students had developed. Hence, we decided to use student-generated categories to describe the findings.

1. Big differences between individuals at the beginning and the end

Responses in this category described how the population of birds at the start of the simulation looked different from birds at the end of the simulation. For instance, one response in this category read "Depending on how similar the parents are, the offspring could var[y] quite a bit, the final generation had introduced new variations of traits relative to the first generations or their ancestors".

This pair described an outcome in two ways: one, the similarity in traits of the parents influences what the offspring will look like, and two, the final generation manifested different variations and looked different overall from its ancestors.

2. Changes gene pool

Responses categorized here referred to change in the gene pool over time. For example, one pair wrote, "When you partake in selective breeding, you are altering the gene pool. The frequency of traits change. Less popular traits become more common if they're desirable".

This pair reasoned that engaging in selective breeding involves changing the gene pool of a population in terms of frequency of traits. Even infrequent traits can become more common if they're desired.

3. Offspring with desired traits

The responses in this category indicated an understanding that through selective breeding, some traits would be removed from the population, while others would be retained. By way of example, one of the responses read "Outcomes of selective breeding are that the "bad" traits are gone and the "good" traits are still remaining. You could see this when we breed the bird."

These findings suggest that overall, in Year 2, student descriptions of outcomes of selective breeding included an emphasis on populations changing over time, and also represented multiple levels of the population. Moreover, we did not see any instances of descriptions from categories 1 and 2 from Year 1.

Discussion & Implications

At the start of this paper, we framed the experience of a participatory simulation in terms of "diving in" and "stepping out" to develop a deep understanding (Ackermann, 1996). The data we have described in this paper facilitates a closer examination of students stepping out from the participatory simulation in pairs to reflect on what they learned. The findings of this study suggest that our three design principles supported productive reflections on stepping out: 1.) Providing explicit representations of students' shared experiences, 2.) Providing access to an underlying third level of alleles, and 3.) Supporting transparent rules of interaction.

Conclusion

In this study, we investigated how specific design decisions for a part-sim designed to support learning about selective breeding in small groups, influenced learning at the level of the individual, and the level of pairs within each group. Prior work has found that this particular part-sim did support group learning about mechanisms of artificial selection as students were engaged in the activity (Wagh & Wilensky, 2012b). However, this work also found that at the individual level, students had trouble abstracting trends from the activity. This led to redesigning the group experience by in three ways: providing each group with concrete records of their shared experiences in the activity in the form of plots, providing each group with access to more information such as information about genotypes, and finally, making rules transparent to ease the group experience of using the part-sim. In reporting data from the second iteration, we analyzed learning at two levels: first, briefly at the level of the entire class by looking at the three big categories of outcomes that they abstracted from their experience, and second, at the level of pairs from each group. In future work, we would like to analyze data from whole-class discussions to closely investigate sense-making at the level of the entire class.

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