Seeing patterns of change: Supporting student noticing in building models of natural selection

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Abstract

Building computational models is powerful in enabling sense making of mechanisms underlying phenomena. However, an important step towards building such understandings is noticing relevant patterns in the phenomena. In this paper, we examine student noticing in the context of a model-building activity in the EvoBuild project. EvoBuild is a construction toolkit designed for middle school students to build models of evolutionary processes. We draw on data of 7th grade students working on an EvoBuild natural selection activity in their science class. Specifically, we report on three cases of pairs of students working on the activity to examine students' noticing and sense-making of trait-specific population-level trends in their model. We describe two emergent themes that students need support with: noticing trait-specific trends and verifying observations. Based on episodes from these cases, we present subsequent design revisions made in light of this analysis.

Keywords agent-based modeling, representations

1. Theoretical Framing

Rapid advances in computer-based technologies have catalyzed the adoption of computational modeling into STEM education. This adoption resonates with the spirit of Constructionism: to provide learners with opportunities to build external artifacts that externalize their intuitive conceptions, rendering them for debugging and revision [1], [2]. Moreover, building computational models makes mechanisms underlying a phenomenon more accessible to learners [3], [4].

We would argue that an important step towards building such understandings would be *seeing* relevant patterns in the models – knowing where to look and what to look at. On the one hand, modeling can enable students to draw on intuitive resources by working with representations that amplify [5] disciplinary ideas, making them visible and useful [6]. On the other hand, learning to see relevant patterns involves negotiated meanings among learners, and the available representational tools, and cannot be taken for granted [7]. This aligns with the notion of disciplined perception: the idea that novices can learn to navigate through the complex and diverse ways of interpreting representations used in a discipline with support from more experienced members of the discipline [8]. One way of easing the tension is designing representational infrastructures that foreground disciplinary ideas, yet are transparent and intuitively accessible to learners [9] to facilitate student noticing.

In this paper, we describe student noticings of microevolutionary change while building an agent-based model of natural selection in the context of the EvoBuild project. EvoBuild [10] is a construction toolkit designed for middle school students to construct agent-based models (ABMs) of evolutionary processes. It builds on nearly a decade of work of using ABMs to help students learn about evolution. We will briefly review this work here, and then go on to describe EvoBuild.

ABMs have been extensively used with middle school, high school and undergraduates to learn

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about all kinds of evolutionary phenomena [11]–[15]. These projects resulted in increased understanding of how individual mechanisms can lead to population level evolutionary changes. More recent work has expanded on the representational affordances of ABMs and participatory simulations to harness sophisticated understandings of evolutionary change across multiple levels (such as the gene, individual, and population) [NSF] [16], [17]. Much of this work has focused on learners *exploring* a model built by an expert. Our goal in the EvoBuild project, on the other hand, is to engage middle school students in *building* models of evolutionary change. Here, we describe the specific EvoBuild activity that students in this study were working on, and then present our research questions.

2. EvoBuild

EvoBuild is a construction toolkit designed to engage middle-school students in building ABMs of evolutionary phenomena using block-based primitives [10]. It has been built using DeltaTick [18], [19], a blocks-based programming interface for NetLogo [20].

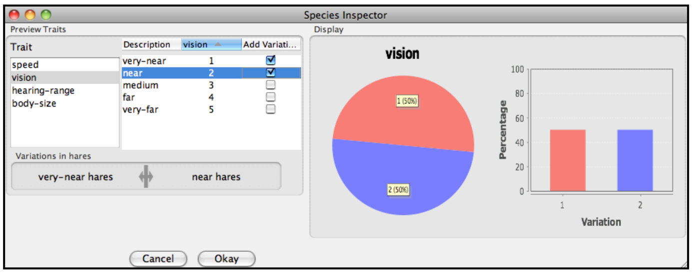

Figure 1: Adding traits & variations to a species

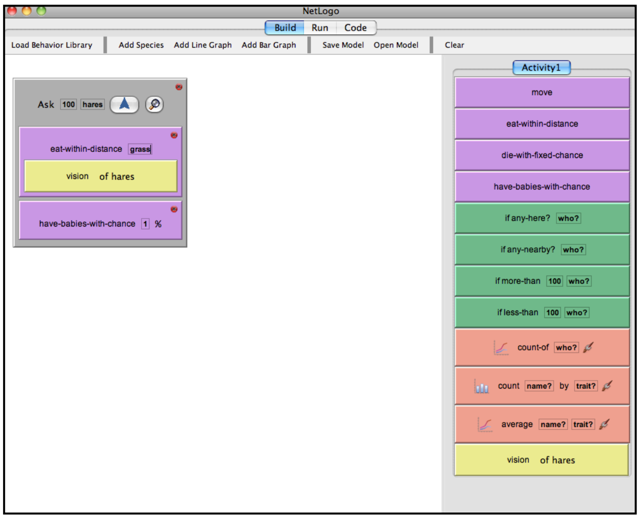

Figure 2: Adding behaviors for species

In the specific EvoBuild activity described in this paper, students built a model to investigate how predatory selection pressures might result in a change in the average speed of a prey population over time. This building was motivated by a seed model shown to the class at the beginning of the activity. In the seed model, a breed of bugs that varied in speed, was being hunted by birds. Both birds and bugs moved about randomly. Birds and bugs in the model also reproduced. The faster bugs were more likely to run into and get eaten by predators. Hence, over time, the average speed of bugs declined over time as there were more bugs that were slow than fast. The seed model included both a line graph that tracked the bugs' average speed over time, and a histogram representing the instantaneous distribution of speed in the population. When the model was demonstrated, the teacher helped students interpret both representations. This seed model was used as a springboard to discuss rules being executed by the agents in the model. Students were asked to build a model to explain how and why the average speed of prey was decreasing over time. They were given a worksheet to guide them through the activity and use of the software.

To build their model, students would first add a species (*breed* in NetLogo parlance). Students would then add a trait, select variations of the trait to include in the population, and specify the initial distribution of the variations in the species (Figure 1). These traits operated as genetic traits, and remained fixed in an agent's lifetime. Students could then specify rules for their species, and add plots to their model track population-level trends (Figure 2).

Students had two built-in supports to notice trait-specific changes in the population. They could add three kinds of plots in their model: line graphs to track number of individuals of a species and the species' average speed, and a histogram to plot distribution of speed variations. They could also select to view the speed variation value for each individual appear as a label next to the individual as the model was running. For e.g., a label displaying *1* would appear next to an agent whose speed variation was 1.

2. Research Questions

The research question is centered on examining the ways that students noticed trait-specific population-level change in their model. This was particularly important in this activity for a couple of reasons. Because the activity was designed to facilitate learning about natural selection, a crucial first step would be for students to *see* the presence or absence of change in the population to begin to develop possible explanations for the same. *Seeing* the presence or absence of change would provide opportunities to reflect on *why.* Moreover, because students were building their own models, they could decide which, if any, plots to include in their model. Though guidance was provided in the accompanying worksheets, we did not have direct control over what representations students had available to them when running their models. Following from this, our research question was: How did students come to notice trait-specific population level trends in their model? I.e., What representations in their model did they attend to, and how did they make sense of these representations?

3. Methods

3.1. Data Collection

The data reported in this paper is drawn from one implementation in a design-based research study [21] to iteratively test and refine the design of EvoBuild. This implementation was conducted in two 7th grade science classes at a school in a midwestern suburb in the United States. Students worked in pairs to build their model over two class periods. Each class was about 40 minutes long. Video data of students building their models was recorded using Camtasia to capture students' onscreen activity and their interactions with each other. Students' models and worksheets were also recorded. Two researchers were present in each class to take field notes, answer questions, and assist students with technical difficulties.

3.2. Data Analysis

The first author of this paper viewed Camtasia videos of all students. Episodes for closer inspection were identified by demarcating segments relevant to three specific focal themes: adding or modifying rules for agents, noticing and attending to trends in the model, and describing mechanics underlying trends in the model. Though the segments were not entirely exclusive and often overlapped, the themes helped coarsely categorize and distinguish the episodes from each other.

In this paper, we examine episodes relevant to the theme of students *noticing* population-level change. In particular, we focus on three purposefully selected cases of pairs of students working on the activity. Case 1 (Ally and Angel) was selected because the trait-specific dimension of population-level change was not visible to them until being explicitly asked to add a plot. Case 2 (Andy and Nikhil) manifested an exemplary trajectory through the activity that we intended to strive for. Case 3 (Sonia and Cyril) contrasted with the other two cases in ways that offered insight into possibilities for design revisions that had not been considered previously. The three cases together were fairly representative of other students' work.

4. Findings

We present a description of relevant episodes from each case, followed by a summary of the case.

Case 1: Ally and Angel

On Day 1, Ally and Angel built a model with a predator species called "Supercats" and a prey species called "Pegelimos". They added the trait, speed, and all five available variations of speed to both predators and prey. The encoded rules were: both predators and prey moved around at a speed specified by their trait, if a prey individual was next to a predator, it would get eaten, and predators and prey both had a 1% chance of reproducing at each tick. Their attention was primarily focused on the total number of prey as they tried to debug their model to prevent them from dying out.

Towards the end of Day 1, in an attempt to draw their attention to how specific variations within the population were faring, a researcher suggested they add a plot to track their species over time. Until this point, Ally and Angel had focused on trying to retain both predators and prey populations in their model. In response to the researcher's suggestion, they added a line graph to plot the average speed of the predator and prey population. When they ran the model this time, their plot indicated that the average speed of the prey population was decreasing, while the average speed of the predators remained constant because the predators were not dying or reproducing. However, Ally nor Angel seemed to ignore the plot and did not explicitly attend to these trends. The next episode described here suggests that they had not noticed them at all until this point.

In the middle of class on Day 2, Ally noticed the histogram on the seed model, which was projected on an overhead screen in setup state. She suggested that they add one to their model. The rules of the model had not changed much, and hence the resulting aggregate trend was very similar: the predators' average speed stayed constant, and the prey's average speed continued decreasing until all the prey died out. When they ran the model, their curiosity was piqued on noticing this trend:

1 *[Ally and Angel add a histogram to track the prey population's speed and*

2 *watch the model run]*
3 Ally: Their speed is decreasing and--omg, all their speed is decreasing. Yep, and they're all dead.

As they ran their model, prey individuals in the model were dying out, and the overall height of individual bars in the histogram was decreasing. However, generally, there were more individuals that were slow than fast. Ally noticed the changing histogram and was surprised by the trend (Line 3, *omg*). Her surprise suggested that she had not previously noticed this trend though they had run the model several times with a line graph depicting a very similar trend. It is unclear from her comment in this excerpt whether she interpreted the changing histogram as representing a decrease in each individual's speed or specific sub-groups dying out (Line 2, *their speed is decreasing*). In later episodes, she interpreted the histogram in terms of how specific variations in the population were faring (e.g., "all the faster speeds are dying off").

Right after this episode, Ally and Angel decided to add a histogram to track speed of the predators. On running the model, they were surprised that the predators' speed stayed constant through the simulation:

4 Ally: Their speed stays the same.
[Ally changes predator label from "none" to "speed" while the model is running]
5 Ally: *[Sounding surprised]* But how… can that be possible that their
6 speed stays the same?
7 Angel: Cause they don't have to run away—cause they don't have to run
8 away from the supercats.
9 Ally: And they don't get eaten.
10 Angel: Yeah.

On running the model, Ally noticed that the speed of the predator population stayed the same and sounded surprised by this observation (Lines 4-6). Perhaps to verify this observation, she turned on the label display for the predators as the model was running, and wondered out loud how that was possible (Lines 5,6). Angel offered a possible explanation - the speed stayed the same because predators didn't have to run away from the prey. Ally further explained that they don't get eaten.

Summary of Case 1

How Ally and Angel noticed and began to make sense of population-level patterns in their model is noteworthy. Through their initial workings on the activity, their attention was primarily focused on the dwindling prey population. In an attempt to refocus their attention to another dimension of change - how specific variations in the population were faring - a researcher suggested they add a plot to their model. The line graph they subsequently added to track average speed of both populations did not tune them into trait-specific changes in the populations. In contrast, the histogram representing trait distributions in both prey and predators immediately made salient trait-specific changes to the collective in the model. Perhaps more importantly, noticing a surprising trend in the histogram prompted them to begin developing mechanistic explanations. Though their explanations had not fully developed in this episode, it marked an important beginning in helping them forge connections between change in population and encoded rules in the model. Finally, Ally's spontaneous use of the labeling feature to verify a trend that was surprising to them suggested a move towards seeking verification of a trend in the plot from the model world itself.

Case 2: Andy and Nikhil

Andy and Nikhil's model had a prey species named Buddernaug, and a predator species named Steve. Five variations of the trait, speed, were equally distributed in the Buddernaug population. The encoded rules were: the prey and predators each moved at their own speed, a predator would eat a prey when next to it, and both the predators and prey were having babies. They picked up on the suggestion of adding a histogram in their worksheet and ran their model. On running their model, they noticed something unexpected:

10 Andy: *[Starts running model. Notices the changing shape of the histogram that he had*
11 *just added as the model runs]* Ah this is kinda cool.
12 Nikhil: Well that's sort of weird... this one. *[Points to the histogram - one group died out]*
13 Andy: Uhh, one, one species of them died. Let's keep going until they all die out.

The missing bar in the histogram seemed to surprise Nikhil (Line 12). Andy interpreted the histogram as suggesting that one "species of them" had died out (Line 13). He also expected that if they continued running the model, all the prey would die out (which was contrary to how their encoded rules would play out).

Right after this episode, Andy noticed that the model had 50 predators and 40 prey individuals at setup. He decreased the setting for maximum number of predators in the model to 10. It was unclear whether he made this change because he suspected that one sub-group had died out because there were more predators than prey in the model. After changing the number of predators, they ran the model again:

14 Andy: *[As model runs]* Ok, one died out. That would be a spe-eed .. *[Pauses the model and looks at the histogram to try to figure out the numeric speed value of the variation that died out]*
15 Nikhil: … of fast.
16 Andy: Which speed would that be? Number 4 is ..
17 Nikhil: Fast.
18 Andy: Number 4 is … *[While Andy is thinking, Nikhil resumes running the model]* No dude--
19 Nikhil: No hold on dude, dude, look. *[Pointing excitedly at the histogram, and speaking*
20 *fast]* All the second speed died out, the medium died out--

When one sub-group died out, Andy paused the model to figure out which specific variation had died out from the population (Line 14). Nikhil correctly volunteered that it was the "fast" prey, while Andy tried to figure out the numeric value of the speed of "fast" prey (Lines 15-18). Nikhil resumed running the model, and was excited on noticing that as the model ran, a couple of other variations also died out from the population (Lines 19-20).

While in the first episode, Nikhil and Andy were surprised that *a* sub-group died out, in this second episode, they came to expect that *some* group would die out, and turned their attention to *which group was dying out* (Lines 14-17). They also noticed, much to Nikhil's surprise, that if they continued running the model, other variations would die out as well. From here on, Andy and Nikhil came to expect that the fast variations would die out from the population, and began to make predictions about *which groups would survive:*

21 *[Nikhil tracking the histogram as the model runs]*
22 Nikhil: Oh! Only two speeds remain. The fastest and the slowest. Fastest going to lose.
23 Andy: They're annihilating them.
24 Nikhil: Fastest going to lose.
25 Andy: Oh! Let's see if they all die out cause they're the only one to eat.
26 Nikhil: *[Laughing]* Look at those!
27 Andy: Can they reproduce fast enough, Yeah there's too many of the slow ones. I'm
28 surprised the slow ones... *[Andy clicks "setup" and then "go"]*

At this point in the activity, Andy and Nikhil predicted that the fast individuals would be more likely to die out (Lines 22, 23), and turned their attention to which sub-group/s was surviving (Line 27) and the conditions under which they'd survive (*if they reproduced fast enough,* Line 27). Andy was surprised that it was the slow ones (Line 27-28). A parallel investigation that came to be of interest to them was whether the prey would all die out eventually, or whether they'd reproduce fast enough to remain in the population (Lines 25-27). Following this episode, they investigated this question by varying the number of predators in their model.

On Day 2, Andy and Nikhil shifted their focus to recording the specific heights of the bars to count how many of each of the sub-groups remained in the population after a 1000 ticks. Towards the end of the activity, they explained the trends in their model using the encoded rules.

Summary of Case 2
Andy and Nikhil's workings on the activity warrant attention for a few reasons: Over the course of the activity, they repeatedly revisited a representation through multiple model runs to notice different aspects of the same phenomena as it unfolded in the simulation. These noticings prompted them to ask questions using the encoded rules to make predictions about how they would play out in the model (e.g., will all the prey die out eventually or will they reproduce fast enough). It also led to investigations beyond the scope of the activity by making changes to their model (e.g., lowering the maximum number of predators from 50 to 10). Their noticings triggered sense-making about the mechanics of the model along with additional investigations beyond the activity.

Case 3: Sonia & Cyril

Sonia and Cyril's model had turtles as predators, and fish as prey. Both turtles and fish had variations in speed, and were moving about randomly. Turtles ate fish, and both had a certain chance of reproducing. Their model had three plots: a line graph for count of predators and prey, and two histograms for speed of the predator and prey population. When they were satisfied with their model, they turned their attention to the line graph. However, there was a discrepancy between what the line graph was plotting, and the meanings Sonia and Cyril attributed to it. Having titled it "Average speed", Sonia and Cyril assumed it was plotting average speed of the predators and prey in the model, though the plot actually depicted the number of predators and prey in their model.

On Day 2, while running their model, Cyril noticed an interesting pattern in the line graph, to which he immediately drew Sonia's attention:

29 Cyril: But look at this really- this really interests me. *[Pointing to the line denoting*
30 *rapidly increasing number of turtles in their model]* Look at this fast increase, they're
going to increase, and then they just-

31 Sonia & Cyril together: Drop. *[Laughing at the subsequent drop in the fishes line]*
32 Sonia: That's cool!
33 Cyril: That's cool. Wait, can I stop it? *[Cyril wants to pause the model]*

Cyril and Sonia were excited by the rapid rise of what they interpreted to be the average speed of the turtles (predators), and the subsequent drop in the average speed of fishes (prey) in their model (Lines 29-32). Right after this episode, Cyril paused the model and left it that way until a researcher walked by their table. When he noticed her, he called out to her to show her the pattern.

34 Cyril: *[Speaking to the researcher as he talks about the trend in the line graph]* My
35 hypothesis is that when turtles, they have an increase, the fishes have a decrease.
36 Because the turtles are getting faster and eating them, and then eating the fishes faster,
37 the fast fishes, and then they're making slower fishes still alive. And then when the
turtles get slower, then the fast fishes can get away.

Cyril and Sonia were excited by a particular slice of the line graph: when the average speed (from their perspective) of the turtles increased, the average speed of the fishes (prey) quickly decreased, and vice versa. Noticing this pattern prompted them to develop an explanation to make sense of it: as the turtles got faster, they were eating the fast fish. Hence the slow fish survived, and stayed alive (Lines 34-36). When the turtles got slower, it was easier for the fast fish to escape (Line 37). Cyril did not offer an explanation for why the average speed of the predators would decrease at all.

Summary of Case 3
These episodes from Sonia and Cyril's case are noteworthy for a couple of reasons: First, like the other two cases, they also highlight how *noticing* a pattern that was perceived as interesting triggered the beginnings of an explanation for *how* that pattern might have arisen. A part of Sonia and Cyril's explanation about the prey population did correspond with the rules that they had coded in the model. I.e., the average speed of the prey population was declining because the fast fish were quickly getting eaten by the turtles. They were on the right track in making sense of the model, but they were at a point where the tool could have provided more support than it did.

This latter point also illustrated an inadequacy of the tool: to enable verification of their observations by not making visually salient the discrepancy between the meanings Cyril and Sonia were attributing to the plot, and what it was actually plotting. Though they could have turned on the label feature, the labels, at quick glance, were not visually salient enough to help them notice the discrepancy between their interpretations of the plot, and the trend in the model.

6. Discussion

The three cases brought to light design issues relevant to supporting students in *noticing* patterns. Across all cases, *seeing* a trend marked an important beginning towards using encoded rules to develop explanations for the trend. While in Ally/Angel and Sonia/Cyril's case, seeing an interesting pattern immediately triggered the beginnings of an explanation, in Andy/Nikhil's case, it was intertwined with successive episodes of noticing different aspects of the same trend. This difference might have been due to the point in the activity they were – Ally/Angel and Sonia/Cyril noticed a trend they were intrigued by only in the middle of the second class period, while Andy/Nikhil spotted an interesting trend early on in the activity. These observations foregrounded the need to explicitly support students' noticing of trait-specific patterns in the model throughout the activity.

In addition to supporting *noticing,* the episodes brought to light the importance of supporting a complementary practice, *verification*. Ally and Angel spontaneously used the label feature to verify a trend they found surprising in the model – that the predators' speed stayed constant. On the other hand, Sonia and Cyril attributed meanings to a slice of the line graph that did not correspond to the trend in their model. While we would argue that their interaction by itself was not unproductive – Sonia and Cyril were reasoning in productive ways about their model - the tool could have supported verification to nudge them further along in sense-making about their model. The presence of verification in Ally/Angel's interactions, and its absence in Sonia/Cyril's, led us simultaneously to recognize the importance of supporting verification, and acknowledge the inadequacy of the current support in EvoBuild.

These concerns – of supporting both noticing and verification - led to two design revisions in EvoBuild. First, students have access to an agent-based distribution formed on the model world view at the click of a button. This is available at all times, regardless of the particular model students have built. The representation finds support in other work that has grounded students' understanding about evolutionary change in distributions [22], [23]. Second, each trait is related to a physical structure denoted in a visually salient way. For example, the trait *speed* has been changed to *leg-length* and is denoted by a stick corresponding to the length against the agent. These revisions can be seen in the figure below.

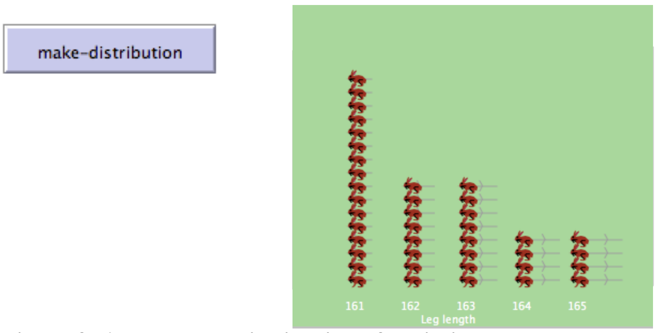

Figure 3: Agent-based distribution of variations

In future work, we are interested in examining how students use this representation to notice changes, and bridge meanings to other representations in their model that denote the same trend.

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