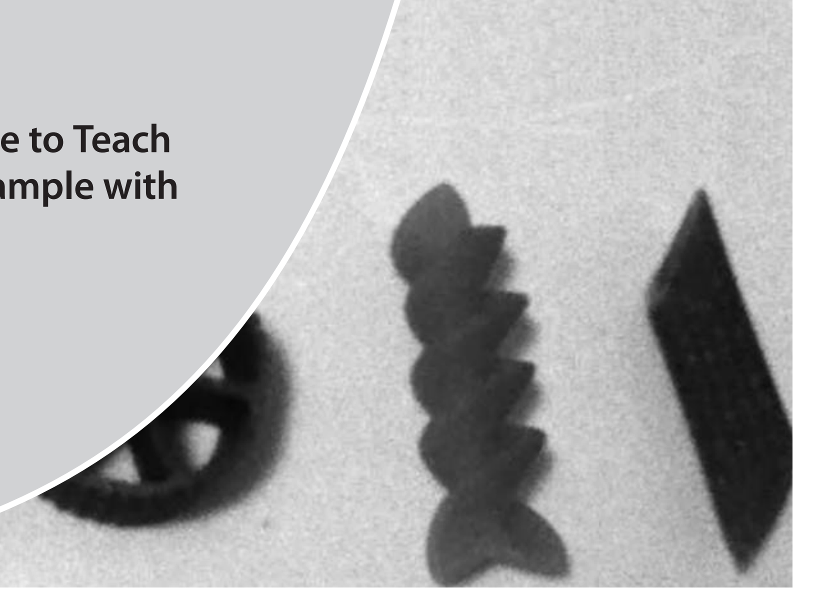

HOW-TO-DO-IT

Using the FAR Guide to Teach Simulations: An Example with Natural Selection

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Abstract

Engaging students in a predator–prey simulation to teach natural selection is a common activity in secondary biology classrooms. The purpose of this article is to demonstrate how the authors have changed their approach to teaching this activity from a laboratory investigation to a class-constructed simulation. Specifically, the authors drew upon a research-based teaching tool (FAR guide) to help students understand how the simulation is analogous to what happens in nature. Teaching the activity in this way can help students connect the parts of the simulation to four basic components of natural selection.

Key Words: *Analogy; natural selection; predator; prey; simulation.*

Classroom simulations serve an important function in biology education. Whether they involve the simulation of cell division (Chinnici et al., 2004), denaturation of enzymes (Turner, 2007), genetic change in populations (Brewer & Zabinski, 1999), or ecological principles (Lauer, 2003), they can help students model complex biological processes. However, utilizing simulations in biology classrooms does not guarantee that students will come away with greater conceptual understanding. In addition to actively engaging in simulations, it is equally important for students to participate in small-group and whole-class discussions to make sense of the activity (Goodrum, 2004).

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By their nature, simulations are analogies for what actually happens in the physical world (Harrison & Treagust, 2000). Research suggests that it is particularly important to be explicit when teaching with analogies, mapping all parts of the analogy (analog) to the concepts they represent (target) (Harrison & Coll, 2008). Therefore, we have transitioned to become more explicit with our students about the parts of the simulation that are analogous to what happens in nature. To change our teaching, we drew upon an approach to teaching analogies called the FAR guide, consisting of three phases: Focus, Action, and Reflection (Treagust et al., 1998; Harrison & Coll, 2008). Using this approach has helped us guide classroom discussions in a more purposeful way and has helped our students develop a more coherent understanding of biological processes and mechanisms. The purpose of this article is to share how we have applied this approach to a common simulation to teach the mechanism of natural selection.

Evolution is the theoretical backbone to the discipline of biology. The *National Science Education Standards* call for students in grades 9–12 to understand the basic principles of evolution by natural selection – that organisms with heritable traits best suited for a particular environment are more likely to reproduce and pass their genes to the next generation (National Research Council, 1996). As science education researchers and former secondary biology teachers, we have observed teachers commonly using a natural selection activity in which students act as predators and hunt simulated organisms (prey). Those organisms that naturally blend in with their environment survive and increase in number. Versions of this activity include using paper dots against colored fabric (National Academy of Sciences, 1998) or jelly beans against paper-constructed environments in shoe boxes (Tieman & Haxer, 2007). We use a similar version in which students "hunt" Wacky Mac brand colored noodles in a grassy area (Figure 1).

Earlier in our teaching careers, we used this type of predator–prey activity as a laboratory investigation in which students discover ideas about natural selection from collected data. We have observed other teachers using the activity in similar ways. By taking a closer look at this activity and interviewing students, we found that students often miss the concepts associated with the activity. Specifically, although students can usually assert that some organisms die off because of an unfavorable trait, they often leave out the critical role of differential reproduction and heredity of favorable traits in their explanations of natural selection after completing the activity. We have also found that students have a difficult time explaining the overarching process of natural selection, which includes many interrelated components.

Rather than presenting the activity as a laboratory, we now present it for what it really is – a simulation. We have changed our overall instructional sequence so that students first develop ideas

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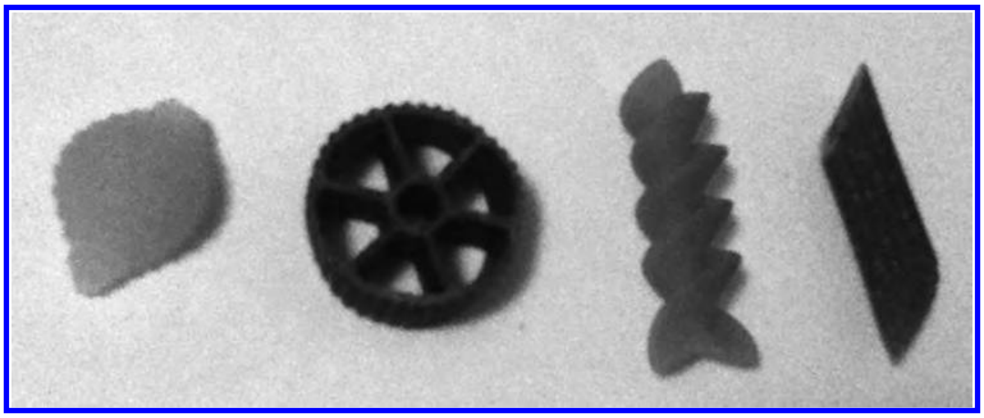

Figure 1. Wacky Mac brand noodle types (from left to right: yellow, purple, orange, green).

representative of what happens in the natural world.

Developing the Procedure

We begin the activity by explicitly telling students that our objective is to simulate the process of natural selection. We then inform them of the general nature of the simulation; noodles will represent a population of organisms of the same species, students will represent predators who feed on the noodles, and the grass will represent the noodle population's habitat. Although we provide the general parameters, we still want to draw on students' ideas and get their input on the procedure. Students are divided into groups, write down an initial procedure, and share their ideas. As instructors, we synthesize students' ideas into statements on which the whole class agrees.

As a class, we first negotiate the initial population (e.g., 40 noodles – 10 of each type). We then discuss the hunting and agree that for each group, one student will hunt the noodles for a designated period (15 seconds), one student will record the number of noodle types, and one student will obtain and distribute the noodles. Next, we agree to a consistent rule to simulate reproduction after each hunt – for example, doubling the number of survivors of each noodle type (if 6 purple noodles remain in the grass, add 6 more). Last, we negotiate the total number of generations (typically 5) and construct a data table to record our results (Table 1). We then go outside to a large grassy area, and students run the simulation. From our own experiences and observing teachers, we have noticed that students get confused, both conceptually and logistically, if they have to reuse noodles that they have "hunted" for the reproduction process. Thus, it is important to have bags labeled "hunted noodles" and other bags labeled "reproduction."

In this simulation, the green noodles will blend in with the grass and thus increase in number throughout the generations. The orange noodles are typically the easiest to see and therefore decrease in number. We have found that the numbers of yellow and purple noodles differ among the students (the yellow numbers are easier to see but smaller in size). After the simulation, students often suggest graphing the data (Figure 2).

about natural selection through examination of real-world data. Using curriculum developed by the BGuILE project at Northwestern University (http://bguile.northwestern.edu), students examine multiple types of data collected from Peter and Rosemary Grant in the Galápagos Islands during the 1970s in relation to the population of medium ground finches. Students eventually come to understand how a drought in 1977 selected against finches with smaller beaks due to a lack of food resources. Following this exploration, we use the predator–prey activity to think more explicitly about the mechanism of natural selection. We believe that our explicit simulation approach allows us to scaffold student understanding through class discussion and, ultimately, provides a stronger foundation regarding the natural-selection mechanism for students to use in future contexts. Below, we share how we have used the FAR guide to teach the predator–prey simulation to secondary biology students.

○ Focus

The first phase of the FAR guide asks teachers to focus on the analogy and consider students' prior knowledge, the analog, and the conceptual target. Regarding students' prior knowledge, we recommend that students enter into this activity having already explored some initial ideas about natural selection, as the purpose of this activity is to model the natural-selection mechanism. Regarding the analog, we view the simulation itself as the analog to the process of natural selection. We have moved away from using paper dots and colored paper because it has been our experience that students can still easily see the dots that are supposed to blend in with the background. By contrast, the green noodles in our simulation are truly difficult to find in the grass even if students purposefully go after them. Regarding the target, we assign four basic components of natural selection – variation, population constraints, differential reproduction, and heredity – as the conceptual target. To help guide students to think about these components, we first ask them to consider more directly how each part of our simulation corresponds to what would happen in nature (which we term "concrete targets"), and then use those examples as a bridge to develop the basic components of natural selection.

○ Action

The second phase of the FAR guide asks teachers to use the analogy in the classroom. We discuss the administration of our simulation in three parts: (1) developing the procedure, (2) mapping analogs to targets, and (3) discussing ways in which the simulation is *not*

Mapping Analogs to Targets

When the simulation is complete, we return to the classroom and students share their data. We note the general commonality of their results (green noodles increasing, orange noodles decreasing). Next, we discuss how the purpose of the activity was to simulate what happens in nature, and therefore we need to think about each part of the simulation and how it links to something in the natural world (see Table 2 for summary). We ask students to create a chart with one column labeled *simulation* and the other labeled *nature*. In this way, we are explicitly mapping the analogous parts of the simulation to a concrete target. We revisit some examples previously mentioned when introducing the activity (e.g., the original 40 noodles represented the initial population of organisms). We then ask student groups to come up with as many examples as they can by rereading the procedure and filling out their charts.

Again we ask students to share their examples of analogs and targets. It is helpful to keep a running tally on the board or projector

Table 1. Sample student data table.

Generation	Activities	Yellow	Purple	Orange	Green
1	Starting population	10	10	10	10
2	After Hunt (# surviving)	6	6	3	9
	Reproduce	12	12	6	18
3	After Hunt (# surviving)	7	5	2	13
	Reproduce	14	10	4	26
4	After Hunt (# surviving)	9	5	3	19
	Reproduce	18	10	6	38
5	After Hunt (# surviving)	9	6	2	24
	Reproduce	18	12	4	48

Note: Students graph the numbers in columns 3–6.

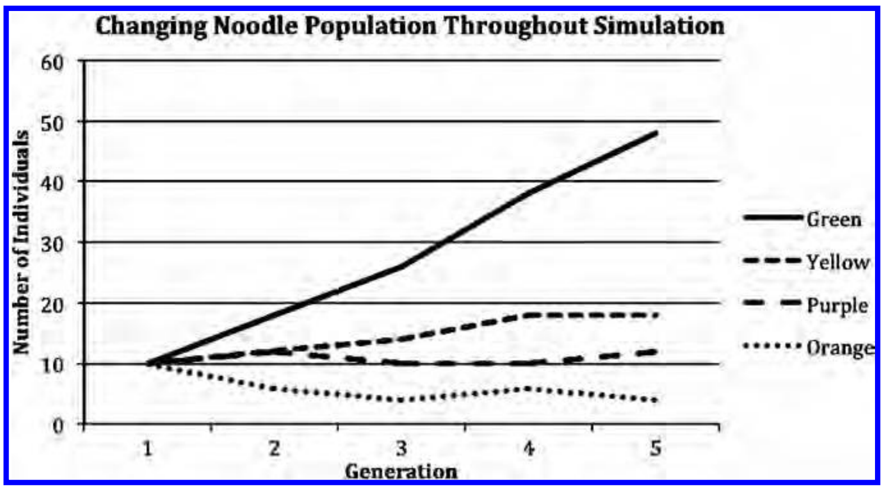

Figure 2. Sample student graph.

screen. We have found that students' initial examples focus on the more concrete aspects of the simulation. Students often state that the colors and sizes of the noodles represented different variations of a trait, picking up the noodles represented predators hunting a population, and adding noodles represented reproduction. For the last simulation step, students may relate the changing numbers of the noodle types to a hypothetical example in nature. As an example, students have suggested that snakes with colors similar to their environment will increase in number because they can more easily avoid bird predators. We use this type of answer as a bridge to discuss what is happening on a more conceptual level. Specifically, we ask "How exactly would the snakes increase in number?" and this leads to classroom consensus that organisms with favorable traits for a particular environment are more likely to survive and reproduce. We follow up by asking "How will this affect the population over time?" and that leads us to discuss more explicitly the consequences of differential reproduction and how it can change the genetic make-up of a population.

Once students have mapped the analogs in the simulation to the targets in nature, we then ask them to link the concrete target to basic components of natural selection – our conceptual target. We pose the question "What conditions are necessary for natural selection to occur?" We provide scaffolding by first asking "What can we say about the 'organisms' in our simulation?" Eventually, students will suggest that there were different noodle types, and we write *variation within a population* on the board. We ask student groups to read through our target list and consider other conditions that were necessary for natural selection and then facilitate a whole-class discussion. We conclude the discussion by matching the four components of natural selection to the appropriate concrete targets already listed on the board (see Table 2).

Students often suggest predation as a necessary condition of natural selection. We point out that the predators in our simulation imposed a constraint on the population such that not all organisms survived to their fullest maturity. We ask them to think of other possible constraints (climate conditions, natural disasters, lack of resources) and write down *population constraint* as the second component. Students may also say that some organisms survive and reproduce while others do not. We use such responses to discuss the role of *differential reproduction* and the subsequent *heredity* of favorable traits as the third and fourth components of natural selection. Using this approach allows us to match our terminology with ideas constructed from the class.

How the Analogy Breaks Down

In line with Harrison and Coll's (2008) approach, it is important not only to map the analog to the targets, but also to explicitly discuss how the analogy breaks down. We therefore ask students to consider ways in which our simulation is misleading or oversimplifies natural selection. Some examples include the following:

- Populations are often larger than 40 individuals.
- Physical color is not the only trait that could be selected against.
- Physical traits often have more than four variations.
- We did not account for organisms dying of natural causes.
- Hunting and reproduction do not always occur one right after the other.
- We oversimplified reproduction by doubling the population number – depending on the species, reproduction rates vary.
- The time frame is greatly abbreviated – significant changes in populations may not occur in five generations.

Discussing these issues allows students to begin developing an appreciation for the complexity of natural selection, which can be further explored with future activities or investigations.

Table 2. Linking simulation steps, analogs, and targets.

Simulation Steps	Mapping Analog to Targets: Parts of Simulation (Analog)	What Happens in Nature (Concrete Target)	Components of Natural Selection (Conceptual Target)
1. Students obtain a bag of 40 noodles of different colors (10 yellow, 10 orange, 10 purple, 10 green)	Bag full of 40 noodles	Population of organisms of the same species	
	Noodles have different colors and shapes	Different physical expressions of traits within the population	Variation within a population
2. Students spread out 40 noodles over a small area of grass	Grass	Environment in which the population lives	
3. Student approaches grass and picks up as many noodles as s/he can in 15 seconds	Students picking up noodles	Predators hunt organisms	Population constraint
	Picked-up noodles	Hunted organisms	
4. Students calculate the number of noodles remaining in the grass	Noodles remaining in grass	Organisms that survived the hunt	
5. Students double the number of noodles of each color remaining in the grass and record the new population numbers	Adding noodles	Surviving organisms reproduce	Differential reproduction
	New numbers of colored noodles	Next generation of the population	
6. Students repeat steps 4 and 5 multiple times	Multiple rounds of picking up and adding noodles	Multiple generations	
7. Students observe and graph the changing numbers of different-colored noodles throughout the simulation	Some noodles decreased after multiple rounds (orange); some noodles increased after multiple rounds (green, yellow)	Some organisms were seen more easily than others; those that blended in to the environment were more likely to survive and reproduce	
	Percentage of different noodle types in last generation is different from initial generation	Change in overall genetic make-up of the population	Heredity

○ Reflection

The third and final phase of the FAR guide asks teachers to reflect on the analogy after using it in the classroom, considering whether or not it was useful and possible improvements for the future. Compared with the laboratory investigation approach, our simulation/analogous approach to this particular activity has resulted in a positive shift toward helping students understand the mechanism of natural selection. We attribute this to the process of explicitly mapping analogs to targets, which provides a scaffolding tool to help students make the conceptual leap to basic natural-selection components.

To understand a mechanism is to be able to simulate the events or processes in one's mind and then use that mental model to make predictions in novel situations (Chart, 2000). This simulation provides an experience to which students can mentally refer when thinking about natural selection. After using this activity, we recommend presenting additional real-world phenomena to students (e.g., peppered moths during the industrial revolution) so that they have the opportunity to use their understanding of natural selection developed from the simulation to continue predicting and interpreting what happens in nature. In addition, we encourage biology educators to consider how the FAR guide might be useful in teaching other classroom simulations to improve conceptual understanding of biological phenomena.

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