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Teaching Evolution: A Case of Overcoming Misconceptions

Context and Students:

I teach at a public high school in Palo Alto, California. Biology 1A is this school's middle-level biology class. Biology is required for graduation, and most students take Biology 1A. Most of my students are sophomores, and a few are juniors. Most are white or Asian. All but two students appear to be native speakers of English. My class contains 12 girls and 19 boys. They are a very vocal group, and fun to teach.

Analysis of the Content:

Starting right after winter break, we began a unit on evolution. The main content objectives for the students were understanding of:

1) indirect evidence for evolution, such as using fossil remains to infer evolutionary relationships;

2) direct evidence for evolution, such as examining allele frequencies in populations using the Hardy-Weinberg equations;

3) evolution and adaptation, by seeing how organisms have various physical structures that serve certain functions that help them survive in their environments;

4) natural selection: that particular organisms which are favorably adapted to their environments tend to survive at higher rates, while those less well-adapted tend to die out. Well-adapted individuals also tend to have more offspring than their less well-adapted competitors, and these descendants tend to inherit their ancestors' favorable genes. Thus, over time, useful adaptations become common in the population, and unfavorable ones rarer.

Before winter break, we completed a unit on genetics. The students learned about genes and how they result in phenotypes, about inheritance patterns, mutations, and genetic disorders. We chose to teach evolution at this point because it is a natural continuation of the study of genetics. Evolution deals with change over time as a result of genetic variation and change.

Intentions:

After the first week of the unit, I thought everything was going quite well. The students produced fine evolutionary trees for the first activity, and their presentations seemed to indicate that they understood how to infer evolutionary relationships. The mathematics of Hardy-Weinberg equilibrium bogged down some of them, but I thought they at least understood that the equations represented alleles, and that allele frequencies might change over time. We ended the first week of the unit with a short video comparing the evolutionary theories of Lamarck and Darwin. It contained a vivid illustration of Lamarck's theory - a cartoon of short-necked giraffes straining to reach tall treetops, growing longer necks, and having taller offspring as a result. The students laughed at the ridiculousness of such an idea. The video continued, describing Darwin's theory of natural selection - how particular organisms with adaptive traits survive to pass their genes on to future generations.

At the start of the second week, we assigned for homework a worksheet on bacterial antibiotic resistance, as a way to connect environmental adaptations to natural selection and evolution. The worksheet described two experiments that involve exposing cultured bacteria to antibiotics (see attached handout). The idea was that when bacteria are exposed to penicillin, most die, but a few bacteria may have a variation that enables them to survive. By gradually increasing the dose of penicillin, and culturing the few survivors each time, one can produce whole colonies of bacteria that are extremely resistant to penicillin. The point is that a random mutation enabled some of the original bacteria to survive, and that they alone could leave descendants. Thus, at the end of the experiment, all the descendants had antibiotic resistance. The mutation that conferred this resistance was there all along, but the presence of penicillin made it advantageous, because only those who had it were able to survive and reproduce.

I liked the activity. It seemed like a nice, straightforward way to show how favorable genes can be inherited through generations while unfavorable genes die out. I figured the kids could do it for homework without too much of a problem, and we could do a quick in-class correction and discussion about it to clear up any confusion.

Interactions and Difficulties:

The day after we assigned the Bacterial Resistance homework, we did not have time to go over it in class. My cooperating teacher decided to collect in anyway and check it off for completion, and we would give it back and go over in class the following day.

I took the papers home with me that night. I checked off the names of the students who had turned them in. Casually, I began to read a few. I was amazed at what I saw.

In evolutionary theory, there is a subtle but crucial difference between the theories of Darwin and Lamarck. Darwin stated that random differences between individuals affect fitness, and that more fit individuals tend to survive and reproduce. In contrast, Lamarck theorized that organisms *become* more fit *in response* to their environment. The difference is that between giraffes who *happen* to have longer necks surviving better than those that do not, and giraffes actually *growing* longer necks because they *need* them to survive. My students had agreed the week before that the latter idea was preposterous - that obviously you don't get taller just because it's useful to be tall, and certainly, you don't have taller children as a result.

Even so, on paper after paper, my students' answers showed Lamarckian reasoning. Chad, one of my most vocal contributors in class discussions, stated, "Over time a resistance was built up because if they didn't they would die off." Janet, another very active participant in class, wrote, "... in the bacteria which was not originally resistant, resistance evolved for the offspring because experiments showed that the penicillin had to be stronger for each generation." These responses imply that the bacteria *developed* antibiotic resistance *because they needed it in order to survive*. This is precisely Lamarck's theory of acquired characteristics. Chad and Janet are two of my best A students, and their errors in reasoning were similar to those of the vast majority of their classmates. The same students who laughed at the video of the giraffe stretching it's neck used exactly the same reasoning to explain antibiotic resistance. The logic I assumed they had adopted fell apart when separated from the familiar example with the funny cartoon.

I was disappointed, but I was excited that all was not lost. Due to a rather amazing set of coincidences, I was armed with the data I needed *before* the in-class correction scheduled for the following day. I could plan what to say to confront my students' misconceptions about evolution and adaptation.

New Interactions:

I began class the next day with an in-class correction on the Antibiotic Resistance worksheet. As I normally do, I asked the students to volunteer answers to the questions, and filled in main ideas as we went along. They seemed to understand the design of the experiment, and had no trouble with the first five questions. On the sixth question, "What can you conclude from the results of this experiment?" Derek answered, "The bacteria developed a resistance to the penicillin." That was the kind of answer I was expecting, and I said we would come back to that point. Elizabeth added, "The penicillin made the bacteria more resistant - they got more resistant so that they could survive." At this point, I tried to make my point about how adaptation actually works.

I reminded them of the video we watched, with the cartoon of the stretching giraffes. I asked them what they thought about it at the time. Chris answered, "It was funny." I pressed on, "Did you guys decide that it made sense, or no?" Their general reply was, "No!" I reviewed Lamarck's theory with them, that organisms grow what they need in order to survive, and pass that trait on to their offspring. I asked them again if they agreed with this idea, and again, their answer was no. I paused, then continued, slowly, "Do you kind of see... that saying the bacteria *developed a resistance* to the penicillin... in order to survive... is kind of like saying... that the giraffes grew taller necks *so that* they could eat from the tall trees? Do you see that this is the same argument?" I paused again, looking anxiously for their reaction.

On a few students' faces, I could see a disconcerted consideration of that point, as if they were realizing the connection. On most of the faces in the crowd, I saw blank incomprehension. Franzo raised his hand, and stated, "Well, when you say the bacteria 'developed resistance,' what you're really saying is that the *population* developed resistance as the weaker ones died." I smiled, because I could see that he understood. Janet raised her hand slowly, wearing an expression of consternation. She asked, "So... it's just random chance that some had the resistance at first, or else they all would have died." I could see a light going on in her mind. She had hit upon a key point, that adaptation is not an intentional process, that the environment may determine who lives and who dies, but that the organisms themselves cannot change just because they need to.

We continued on to the next page, with the experiment demonstrating that antibiotic resistance had been present from the beginning. The students who volunteered could explain the experimental setup and describe how it was different from the original. They also seemed to understand that the original colony A bacterium had penicillin resistance, and that all it's offspring inherited this trait. The last question framed the key concept about evolution: "Did the resistance actually 'develop' in the bacteria?" At this point, more students seemed sure that it did not. Rukmal replied shyly, "They *inherited* it." Ivan explained, "It [the resistance] didn't just show up out of nowhere, the A bacteria had it all along."

I was pleased with the answers I was hearing, but I was concerned that at least half of my students still looked confused or vacant. I could also tell they were losing steam, and we still needed most of the class period for a lab. I closed this part of the lesson by relating the experiments to taking antibiotics, and how if you don't take the whole bottle, you might allow a few resistant bacteria to survive and reproduce. They could make you sick again, or more likely to infect a friend with bacteria that don't respond to antibiotics. Scott asked a great question that told me that he understood the concept: "If the point is that some of the bacteria are resistant anyway, how does taking all your antibiotics make a difference? Won't some of them survive anyway, because they're resistant?" Scott's question told me he understood that the trait existed at the beginning, and that the antibiotics simply made it an advantage.

For the rest of the unit, my cooperating teacher and I reinforced the idea of evolution by random changes at every opportunity. Over the next several days, I noticed more and more student responses compatible with Darwinian thinking. I graded the bacterial resistance worksheets, and saw that several students had modified their original answers in light of the class discussion. However, the majority of the students' answers still reflected Lamarckian reasoning. This was not too surprising because many of my students routinely fail to self-correct their homework. However, I also noticed incorrect answers on many papers where other answers *had* been modified, implying misconceptions, not carelessness.

By the beginning of the next week, it appeared that much of the class could quote the theories of Darwin and Lamarck, in theoretical, glossary-like terms. On the first day, my cooperating teacher offered the students a thought question about acquired characteristics: "Let's take Arnold Schwartzeneger as an example. Let's say he started out looking like a normal guy, but worked out and lifted weights for years and years, and got really big and muscular. Do you think his children would be different as a result?" Several students displayed an intuition for what traits can be inherited. Edoardo commented that, "Arnold's behavior might affect his children's behavior, like if he got them to exercise a lot." Peter added, "They [the children] wouldn't inherit more muscle mass, but they might inherit a faster metabolism, or something like that." Chad seemed confused; he said, "I don't think they'd be born muscular, but their behavior... I don't know."

On the following day, my cooperating teacher posed the question, of poison-resistant pests, "Did the DDT *make* them resistant?" The class answered, in chorus, "No!" Chad responded, "So the ones that happened to have the trait survived, and the others didn't." *At last!* I thought. By this point, at the conclusion of the unit, it appeared that more students "got it" than before. But how could I know for certain?

The results of the multiple-choice unit test were, in my opinion, inconclusive. Out of 25 students, between 1 and 13 students missed various questions relevant to our central concept. Thus, in general, most of my students were producing correct answers most of the time. However, I am in no way certain what I can fairly conclude about their understanding.

<u>Reflection</u>:

I believe the major factor I failed to consider in my teaching is that students do not arrive in my classroom with blank mental notebooks waiting to be filled. They have been little scientists their entire lives, observing the world around them, and trying to figure out why things are the way they are. They observe creatures that seem perfectly suited to their environments. They know about animals preying on other animals, so that only the strongest and fastest survive. They see people, beings of superior intelligence and ability running the world. It looks like everything is *supposed* to be that way.

In teaching this unit on evolution, I was probably battling a long-standing misconception about how organisms came to be the way they are. In my students' minds, their choices determine their fates. Why not so for all living things? Why shouldn't organisms become stronger because they *need to* in order to survive? Why shouldn't living things adapt to their environments willfully, purposefully, because it makes them *better?*

Not only is Lamarck's theory intuitively and emotionally appealing, it is also correct in some cases. A person who lifts weights develops stronger muscles. A person gets sick and develops immunity to a disease. The difference between these situations and growing taller as a result of stretching is not intuitively obvious.

Though not obvious, there is a key difference between "real" evolution and "real" acquisition of characteristics. Traits that are determined by genes are the ones that are operated on by natural selection. *Genes* cannot be changed (at least not under normal circumstances). Some *traits* can be affected by outside influences, but even so, the genes remain the same. I believe that my students had the background in genetics to understand such a distinction, if it were posed to them in that way.

There are other strategies I could have used to help my students internalize the principles of evolution by natural selection. One possibility would be to have my students write about their ideas at the beginning of the unit. For example, they could respond to a question such as, "How did the giraffe evolve its long neck?" Such an exercise would give me a clearer idea of what they were thinking, and would also give them something concrete to reflect on. When they learned new theories that contradicted their own dearly-held ones, they may be able to look at them more objectively. The war of ideas would be more visible.

As far as I could tell, many of my students actually did come away from the unit with the understandings that I hoped they would gain. However, the chapter test really failed to indicate how well my students understood evolution by natural selection. I think an essay question in which the students had to explain the concepts by comparing competing viewpoints would have provided me a better indicator of their understanding. I believe it might also help them clarify in their own minds the subtle differences between the two major theories. An example of such a question could be, "Sharks have several rows of sharp teeth, angled inward. Explain how 1) Lamarck and 2) Darwin would have explained why the shark species developed this adaptation over time."

Nevertheless, even this assessment would not eliminate another very real possibility. As I posed questions to the class about evolution, I got more and more "correct answers" over the course of the unit. However, I cannot know with certainty whether they actually believed, in their heart of hearts, what they were saying. I worry about the possibility that people store their "school facts" in a separate section of their brains from what they *really* know to be true.

I guess my final question is about how to bridge the gap between the real world and the classroom. Worksheets and in-class dialogues are far removed from nature, where wolves chase down the slowest hares. The complex interplay of adaptations battling adaptations is what my students need to see, to experience, in order to believe what I tell them. But how?