TIPS, TRICKS & TECHNIQUES

Teaching Biology with Extended Analogies

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Abstract

All teachers hope that students learn to apply and analyze, rather than simply memorize or parrot back, the teacher's words. One method of encouraging the development of students' higher-level thinking skills is to give learners practice in identifying appropriate analogies for biological concepts, and in forming their own. Analogies focus on the larger concepts we are trying to teach, rather than specific biological details or actual biological examples. They are fun to practice in class, and this practice prepares students for similar test questions.

Key Words: *Analogy; analogies; teaching; biology.*

Most educators are aware of the levels of the cognitive domain first established by Bloom and later revised by Anderson and Krahwohl. Occasionally the distinction between levels can be fuzzy, but it is vital – at least – to distinguish lower levels of thinking, such as rote memorization, from higher levels in which knowledge is applied, combined, or evaluated. It is not wrong to ask basic-level questions of our students – and, in fact, there are many instances in which rote memorization is required – though it is usually preferable not to limit our questions to this level. When students really understand a concept, they are able to apply it to diverse situations, which is a higher learning level than merely being able to parrot a concept back to the teacher. For example, after providing students with various real-life examples of natural selection, I often ask them to pair up and, for two minutes, make up an example of natural selection. They can even use imaginary creatures. Doing this encourages students to apply what they have learned and to integrate the concepts. When presenting their scenarios to the class, we discuss whether they have remembered to include a mutation; whether they have specified how the resulting new allele helps the organism to reproduce, not merely be "big and strong"; and how the frequency of that allele will increase in the population over time. By creating their own scenario, students apply personally relevant principles to new situations, and comprehension of the concepts should thus become more deeply ingrained.

> *Analogies promote higher-level thinking and help students grasp new concepts.*

Because science classes often include abstract concepts, and because analogies relate abstract concepts to ideas we are more familiar with, analogies are ideal for use in science teaching. Analogies promote higher-level thinking and help students grasp new concepts. Analogies are interesting and engaging to students and increase their confidence that they can learn abstract material (Orgill & Bodner, 2004; Orgill & Thomas, 2006). By asking students to describe how an analogy describes a scientific idea, and to point out where the analogy is not quite accurate (no analogy completely reflects reality), we get students to think more deeply about the scientific principle. Then, by forming their own analogies, they apply their knowledge (Orgill & Thomas, 2006). Analogies should not be taken too far and should not become the limit of a student's understanding; this can sometimes be prevented by using multiple analogies combined with other learning methods. For example, we don't want our students' understanding of the mitochondrion to be limited to "the power plant of the cell" (Orgill & Bodner, 2004), although this may be a great place to start. Analogies are useful for both child and adult education. The authors of a middle school pedagogy study note that their students enjoyed analogies but sometimes would rather just learn by answering questions instead, because it took less time. But they point out that if we are to produce creative students who are able to solve personal and societal problems, we need to encourage analogy use to promote the needed creativity (BouJaoude & Tamim, 2008).

We can present new concepts by analogy, and we can also test understanding of concepts by asking students to identify concepts illustrated by analogy, or to form their own analogies. As an exercise, students pick a biological topic we've discussed in class and analogize it to something they are familiar with, explaining and defending their analogy.

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I have found it useful and engaging to present my students with "extended analogy" matching questions, as classroom practice. In them, students must connect a hypothetical scenario to a scientific concept. Like the use of imaginary creatures to support an understanding of natural selection, these matching questions require students to think more deeply about the underlying concepts. These matching sets can also appear on tests. I have learned by experience not to ask overly abstract analogy questions on tests, without first preparing students with practice questions during class time or as homework. But such questions, even on tests, can help students learn conceptual understanding (Jensen et al., 2014). There is a "right answer" for each question, but I encourage students who choose a different answer to explain their reasoning, and if they can defend the logic of their choice, it deserves to be given credit, either verbally (during classroom practice) or in points (on a test).

Here are two sets of analogy matching questions that I use in my college courses, along with my answers. I use these analogies in this matching-question format to test understanding (either informally in class or on a test) after students have studied a concept, but they can also be used to introduce concepts. One of these sets is for an introductory course for nonmajors, and the other is for an advanced course for biology majors.

First, consider the following example from a unit on cellular transport and energetics in the nonmajors course:

○ Cellular Transport & Energetics Scenarios

Answer list:

- Enzyme specificity
- Active site
- Denaturation
- Feedback inhibition
- Diffusion
- Gradient
- Active transport
- Enzyme
- Metabolic pathway

(1) You are bored, so you tinker with your door's lock. When you alter the keyhole, the key no longer fits and the lock no longer works. What part did you alter? (The **active site**. Although the "induced fit" model is more technically correct, the lock-and-key model works well as an introduction for beginning students. Induced fit is just a more flexible lock.)

(2) You melt the lock in a really hot fire, and it no longer works. (**Denaturation**, because you changed the shape of the lock/enzyme.)

(3) Your friend often sets up people on blind dates. In fact, his work has resulted in 50 weddings, but he is still single. (**Enzyme**, because it facilitates reactions but does not itself get used up.)

(4) Your friend gets a job in the zoo working with chimpanzees (which are closely related to humans) but is unable to set them up on dates. Evidently he can only match humans together. (**Enzyme specificity** – enzymes require the correct substrate.)

(5) One hundred thousand people are in a stadium out in the middle of a sparsely populated desert area. (**Gradient** – an area of high concentration and an area of low concentration.)

(6) One hundred thousand people are in a stadium, but when the game is over, they disperse in all directions. (**Diffusion**, because they are moving from an area of high concentration to areas of low concentration in a random sort of way.)

(7) On a tour of a car factory, you notice that cars are made not all at once, but step-by-step down the assembly line. First the chassis, then the engine is added, then the wheels, then the seats, etc. (**Metabolic pathway** – a step-by-step synthesis of a final product.)

(8) You take 100 dogs who dislike each other and force them into a room together. (**Active transport** – it requires energy to make them go where they don't want to go.)

(9) Your robot factory is automated so that when there are too many being produced, some of them will hold down the off switch on the assembly line. But as the robots are sold, there are fewer of them to hold down the off switch, so that eventually the assembly line turns on again. (**Feedback inhibition** – the metabolic pathway can shut off its own production.)

Next is an example of the strategy for a genetics course taken by biology majors who should have a good grasp on basic biology:

○ Genetic Scenarios

Answer list:

- Codominance
- Dominant negative
- Epistasis
- Lethality
- Incomplete dominance
- Maternal effect
- Mitochondrial inheritance
- Pleiotropy
- Sex-linked (or X-linked) trait

(1) The C allele leads people to drive Corvettes, and the V allele of the same gene leads people to drive Dodge Vipers. (Note that this breaks the normal convention for using uppercase and lowercase letters as alleles.) CC individuals therefore drive Corvettes, and VV individuals drive Dodge Vipers. But CV individuals drive both kinds of car. (**Codominance**, because neither allele is dominant to the other; those with both alleles have both traits.)

(2) A mutant chicken has paint glands, so that her eggs come out blue, yellow, purple, and green. In fact, some of this paint penetrates the shell so that the chicks come out colored as well. You might assume that these chicks have a mutation, but they are wild type. (**Maternal effect**,

because it is the mutation in the mother, rather than the offspring, that forms the offspring's phenotype.)

(3) In cookies, the C allele promotes the inclusion of chocolate chips, while the c allele promotes the inclusion of caramel chips. So CC or Cc cookies taste chocolatey and cc cookies taste like caramel. But the rare dominant allele of the S gene promotes a tenfold higher salt concentration than normal, so SS or Ss cookies taste only salty – if you can eat them at all – in spite of which flavor they would otherwise have. (**Epistasis**, in which the actions of one gene block the actions of another. Or two different genes – not to be confused with two different alleles of the same gene – are responsible for one phenotype.)

(4) You have two cars: one runs, and one does not. You would think that using the running car, you could get to work. But the non-running car is parked behind the running car in the narrow driveway, so you cannot get to work. (**Dominant negative**, in which a nonfunctional allele that usually would act recessively exerts a dominant effect, which leads to no gene function.)

(5) In Shenandoah Skunks, the S allele leads to stinkiness, and the s allele is nonfunctional. You cross Ss males to Ss females. Of the offspring, you don't find any that are SS. Turns out, SS skunks smell so bad they die in the womb. But you do find the expected number of Ss and ss skunks. There are *two* situations that should come to mind. (**Lethality**, because SS skunks die; and **incomplete dominance**, because the more S alleles, the greater the smell; SS is stinkier than Ss.)

(6) While driving your car, it suddenly begins to overheat, and, at the same time, the power steering ceases to function. You wonder what the chances are of two mechanical malfunctions happening at once! But your mechanic informs you that a broken belt caused both of these problems. (**Pleiotropy**, in which one mutation has multiple effects.)

(7) Remote control hogging is genetically controlled. Occasionally women have this trait, but usually men are affected. When a man has the trait, his children never do (unless the mother is a carrier or is herself affected). (**X-linkage**, in which traits pass from carrier mothers to sons, and women are not affected unless they are homozygous.)

(8) Female dragons with a mutation that results in very little ATP production crossed to normal males result in offspring that are all mutant. But crossing normal females to mutant males results in all normal offspring. (**Mitochondrial effect**, since the trait is passed on from mothers only. Another hint is the lack of ATP production when the mitochondria are less functional, which the students in this course should recognize.)

Now that you have seen how these extended analogies can be used, you can create your own (and ask your students to create their own) and adapt them for use in different classroom situations in various courses and levels. They will engage both the students and the teacher.

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