ARTICLE

A Socratic Method for Surveying Students' Readiness to Study Evolution

WILLIAM D. STANSFIELD

Abstract

Before beginning a series of presentations on evolution, it would be prudent to survey the general level of students' understanding of prerequisite basic concepts of reproduction, heredity, ontology, and phenotypic diversity so that teachers can avoid devoting time to well-known subjects of general knowledge and can spend more time on subjects that are unknown, forgotten, or misunderstood by most students. This article outlines a Socratic method for surveying and teaching to address these concerns.

Key Words: *Acquired trait; cancer; cellular differentiation; epigenetics; gene pool; genetic fitness; somatic cells.*

In a recent *ABT* article, Williams et al. (2012) related their use of the instructional module Web-based Inquiry Science Environment (WISE) to introduce middle school students to genetics. The WISE Genetic Inheritance Unit includes the following activities: inherited and acquired traits, cell structure and function, cell growth and mitotic (asexual) division, cell differentiation, meiosis and sexual reproduction, Mendel's law of segregation, and use of a Punnett square to determine genotypic and phenotypic ratios in progeny from genetically defined parents. If middle school biology students have experienced the WISE program and/or its equivalent content in lectures or textbook assignments, then we might assume that high school and freshman college biology students would be familiar with terms such as *chromosomes*, *genes*, *diploid*, *haploid*, *gametes*, *genotype*, *phenotype*, *homozygote*, *heterozygote*, *somatic cells*, *germ-line cells*, *dominant and recessive genes or traits*, *segregation of alleles*, *independent assortment of nonhomologous chromosomes*, and others. But teachers should not be surprised to learn that, in the more advanced classes, these terms are unknown, forgotten, or misunderstood by a significant number of students, requiring teachers to correct these deficiencies before proceeding with lectures, textbook assignments, or other activities pertaining to evolution. The present article offers a simple Socratic method to give high school and college teachers of evolution a prior opportunity to evaluate and augment their students' basic level of prerequisite understanding of reproduction, heredity, ontogeny, and the sources of genetic and phenotypic diversity.

> *Students are generally unaware of "what they do not know" until they have been asked specific questions.*

Students are generally unaware of "what they do not know" until they have been asked specific questions. Some colleges are making "courses more active by seeding them with questions, ask-your neighbor discussions and instant surveys" (deVise, 2012). The original Socratic method was the method employed by the 5th-century B.C. Greek philosopher Socrartes of propounding a series of questions with the object of eliciting expressions of opinions in order to establish, or refute, a proposition or conclusion. The Socratic method suggested here consists of a list (List A, below) of statements, propositions, or conclusions designed to elicit from students their opinions regarding the degree of confidence (dc) they have that these statements are true. The scale uses five letters (A–E): A = the statement is true or very likely to be true; dc = 81–100%; B = the statement is more likely true than false; dc = 61–80%; C = undecided or no opinion or statement appears ambiguous; dc = 41–60%; D = the statement is more likely false than true; dc = 21–40%; E = the statement is false or very likely to be false; dc = 0–20%.

There are several ways to use this information. The teacher may present one or more of these statements to the class for discussion. The statements selected would be the ones most directly germane to the lessons that will immediately follow. The teacher then guides the discussion by a "responsive teaching" method akin to that of Levin et al. (2012) to evaluate what students are thinking and how they justify their thinking. This procedure does not allow much time for students to introspectively examine their own feelings or thoughts about a statement more than superficially before taking a position or responding to the arguments presented by others. Because class time is so limited, and to provide more time for students to prepare for class discussions, I suggest assigning the survey as a homework project. Student responses would be entered on a machine-scored sheet with five possible choices per statement, as described above. From this, the instructor would be able to spot responses that deviate most often from currently accepted scientific knowledge, thus indicating more need for discussion in class. This list of statements can be given both before and after lectures, classroom discussions, assigned readings, and/or homework to evaluate the degree of comprehension gain in the interim. In List B, a sample response is

The American Biology Teacher, Vol. 75, No. 2, pages 102–105. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2013.75.2.6

given for each statement, which teachers may embellish or modify with their own knowledge.

This Socratic method deals with many of the same subjects treated by Williams et al. (2012), but also with other more timely subjects that might not have been mentioned in previous classroom activities or assigned textbook reading. Some of the statements in the survey may also stimulate interest in forthcoming lectures or classroom discussions: e.g., cancer; alcohol, drug, and tobacco addiction; obesity; mutations induced by bacterial and viral diseases; epigenetics; blood and tissue transplants between immunologically compatible members of different races or cultures; evolution as a population (gene pool) phenomenon, not one that develops in an individual during its life; age effect on biological fitness; scientifically discredited ideas such as Darwin's gemmule or pangenesis hypothesis; loss of genetic information during cellular differentiation. Thus, the Socratic teaching method has at least three major functions: (1) to engage students in introspection regarding their grasp of fundamental genetic and evolution concepts; (2) to stimulate student interest and thoughtful participation in class discussions; and (3) to allow teachers to evaluate (via pre- and post-surveys) the effectiveness of the method.

The basics of epigenetics should be addressed prior to making the survey. Epigenetics is a branch of genetics that studies how phenotypic variants arise without changing the nucleotide sequence in DNA by turning genes on or off during differentiation from the zygote onward, as well as the day-to-day activity of genes in response to metabolic, homeostatic, and other adaptational needs. A few characters acquired during the life of an individual by epigenetic mechanisms may be transmitted from parents to offspring (inheritance of acquired traits; Stansfield, 2011; McComas, 2012a, b; Stein, 2012), but it is not the general rule we expect in sexually reproducing organisms, and the phenomenon seldom lasts more than one or a few generations without repetitive stimulation. Students should use their knowledge of genetic transmission rather than epigenetic transmission in forming their opinions on the statements presented in List A. Epigenetic mechanisms may not be discussed in biology texts published only a few years ago, so the possibility of the inheritance of acquired characters may need to be addressed via lectures or outside reading assignments. Changes to the nucleotide sequences of DNA (mutations) are, of course, the ultimate source of new genetic variants. Evolution by natural selection depends on heritable genetic variation in a population. Any gene may incur a mutation, but new mutations are usually so rare that they should not be considered as a general mechanism when students form their opinions to statements in the survey.

Being retired from teaching, I did not have the opportunity to use the Socratic method advocated here. Even if earlier I had thought of using it, I would have done so in the hope that it might stimulate excitement and critical thinking in my students, not with the intent of conducting educational research and the publication of a paper. Its use does not require revamping of curriculum or educational objectives. The success of this method may vary from one teacher to another, but teachers will never know if it has pedagogical value unless they try it in their own classes.

○ Addendum

As I was preparing this article for *ABT*, the American Association for the Advancement of Science (AAAS) announced in *Science* (336, 433) its Project 2061 online science tests (http://assessment.aaas.org), containing more than 700 test questions for life science, physical science, earth science, and nature of science. Among the six topics in the life sciences, two are most germane to the present article (evolution and natural selection; reproduction, genes, and heredity). Teachers can use this resource to build multiple-choice tests from items that they select from the site's full database of questions. The tests can be administered and scored online, providing quick feedback for teachers, so they can adjust their instruction to respond quickly to their students' needs. The test questions are appropriate for middle and early high school students. They test for common misconceptions as well as correct ideas. For example, in the unit on reproduction, genes, and heredity, student misconception ID number RHM116, says: "The different cell types (skin, muscle, cartilage, etc.) found in a given individual's body contain different DNA." The percentage of student misconception was 61% in grades 6–8 and 55% in grades 9–12. These kinds of data corroborate the need to access students' misconceptions via the Socratic method or some other teaching method before starting a unit on evolution.

List A

1. Mitosis in humans normally produces haploid gametes, of variable genetic composition, by at least three processes.
2. Because a mother's egg cell is much larger than a father's sperm cell, most children tend to receive more nuclear genes from their mother than from their father.
3. In a population, natural selection normally causes recessive genes to evolve into dominant genes.
4. The most frequent genetic traits in a natural population are, by definition, those produced by dominant genes rather than by recessive genes.
5. If an individual is born heterozygous for a dominant/recessive pair of alleles, yet fails to develop the dominant trait sometime during its life, the most likely cause is the loss of the dominant allele, allowing the recessive trait to be expressed.
6. A single Mendelian gene may sometimes produce more than one trait.
7. A quantitative trait (e.g., size or shape of body parts) is normally produced by the combined action of multiple genes and environmental effects.
8. Cancer-producing mutations that occur in the DNA of skin, lung, colon, prostate, or mammary tissues of parents can be inherited by some of their children.
9. Parents who abuse the use of drugs, alcohol, and cigarettes have a greater chance of inducing these same behaviors in their children than if those same parents had never exposed themselves to such substances, even if their children are raised from birth by foster parents who do not use these substances.
10. Some traits of an offspring may be an approximate average of those of its parents because of the blending of their fluidlike germinal influences. Hereditary characters transmitted in this way normally do not segregate in later generations, producing a relatively stable intermediate phenotype characteristic of some intervarietal hybrids.
11. Children of severely overweight parents might inherit the potential to become overweight or obese but would not inherit this tendency if their parents had dieted back to normal weight before conceiving children.
12. Men who have suffered severe illness from communicable diseases (caused by bacteria or viruses) are more likely to produce genetic susceptibility to these diseases in their children than if these same fathers had not contacted these disease organisms.

13. People who, prior to the conception of children, receive a blood transfusion from a member of a different race, increase their risk of producing children bearing at least some of the characteristics of that other race.
14. Biological evolution is said to occur when an individual changes any of its anatomical, physiological, biochemical or behavioral characteristics in an adaptive response to a new environment.
15. If an individual's "genetic fitness" or "adaptive value" is determined by the number of offspring it produces, then individuals that survive longer than average have greater "genetic fitness" than shorter-lived individuals of the same species.
16. At sexual maturity, small pieces of adult animal tissues (called gemmules) from different parts of the body (e.g., head, torso, arms, legs, liver, lungs, heart) are transported to the gonads (ovaries and testes) and there become incorporated into gametes (eggs or sperms) during their formation. These gemmules become amplified as the embryo grows to regenerate the same general kind of body parts from which they were derived.
17. Modern giraffes have long necks because some of their shorter-necked ancestors had to stretch their necks to reach leaves high in trees during times of food scarcity. This muscular activity required activation of more genes and corresponding incremental activity-induced changes to those genes, which were then transmitted to offspring. Continued activity of this kind over many generations lead to the longer necks we see today.
18. A Punnett square may be useful for predicting the expected genotypic and phenotypic ratios among offspring of parents heterozygous for a pair of alleles, but it is not useful for predicting genotypic and phenotypic ratios from one generation to the next in a population.
19. The only adult human cells that make the protein hemoglobin are red blood cells because the gene for hemoglobin is normally lost during differentiation of other body cells.
20. Harmful or relatively poorly adapted dominant genes are generally more easily removed or decreased in numbers from a population gene pool by natural selection than are harmful recessive genes.

List B

1. This statement is true. Genetic variation in gametes is due to (1) segregation of alleles; (2) crossing-over between linked genes, and (3) independent assortment on non-homologous chromosomes.
2. Gametes (eggs and sperm) of each species normally contain the same characteristic number of autosomal (non-sex) chromosomes and genes. Female somatic cells have two X chromosomes; male somatic cells have an X and a Y chromosome. Female gametes have one X chromosome; roughly half of male gametes contain an X and half contain a Y. Otherwise, the size of the gamete has nothing to do with the amount of nuclear genetic material it contains.
3. A dominant gene may rarely randomly mutate to a recessive allelic form (or vice versa), but evolutionary forces do not direct genes to mutate preferentially from one form to another. Many gene mutations may occur without changing their dominant or recessive nature with regard to one another.
4. The frequency of a gene in a natural population is determined by evolutionary forces such as natural selection, not by the gene's developmental interaction with its alternative allele within an individual.
5. If a recessive trait develops in a heterozygote, it is most likely due to epigenetic inactivation of the dominant allele rather than due to the loss of the dominant allele (a rare mutation).
6. True. This phenomenon is called "pleiotropy." For example, Mendel reported that the color of the pea seed coat is correlated with the color of the flower in which it develops. One gene may produce multiple traits.
7. True. Multiple genes may be involved in producing a given trait such as meat, milk, or egg production in farm animals. Well-nourished plants and animals are more likely to be more productive than those that are starved of nutrients.
8. All cells of a multicellular body other than those destined to become sex cells are called "somatic cells." The notion that DNA mutations originating in somatic cells can be transmitted to offspring via gametes is wrong.
9. Some parents may have a genetic constitution that predisposes them to abusive behaviors. The misuse of substances does not change (mutate) parental genes to make their children become more easily addicted. Addictive parents may pass some of this genetic predisposition on to their children whether or not the parents chose to indulge in substance abuse. If parents or foster parents are addicted and permissive in the rearing of their children, it would probably make it easier for their children to indulge in these risky behaviors, and especially so if they inherited a genetic predisposition to do so.
10. Many quantitative traits in offspring appear to be intermediate between those of the parental types in first-generation hybrids. Genes do not mix or blend with one another (like different colored paints). Their particulate nature is commonly revealed by segregation into a spectrum of phenotypes from one parental extreme to the other in later hybrid generations.
11. Children may inherit a genetic tendency to be overweight from one or both parents whether the parents dieted or not. However, if children are reared in a home where parents serve large helpings of high-calorie foods and/or allow snacking between meals, and do not encourage their children to exercise, these kids would be more likely to put on excess weight than they would have if their food was not so readily available.
12. Both mothers and fathers contribute genes that affect the immune system of their children. The effectiveness of the immune response to different germs may be quite variable from one individual to another or from one time to another in the same individual, depending on both genetic and environmental factors. For example, if a man is malnourished and stressed at the time he becomes infected with germ X, he may not be able to fight off disease X as well as he would if he were in good physical and mental health. The genetic component of susceptibility to infection by germ X that a child receives from its father is independent of whether or not the father succumbed to disease X. On the other hand, if a women had been exposed to germ X prior to having a baby, she would be expected to make antibodies against that organism. Babies of both sexes normally receive antibodies from their mother while in the womb and in the mother's milk postnatally. Thus, babies whose mothers had recovered from disease X would tend to be less susceptible to infection by germ X than if the mother had not contacted germ X previously. These protein antibodies that a baby receives from its mother will gradually be metabolized away, leaving the child dependent on its own immune system for defense against foreign substances.
13. Blood transfusions and tissue or organ transplants involve somatic cells that normally would not affect the genotype of recipients. Mature human red blood cells have no nucleus and, thus, add no nuclear DNA to the recipients. But if a light-skinned person received an immunolgically compatible skin transplant from a

dark-skinned donor, the transplanted tissue would be expected to continue to produce melanin according to its own genotype and appear darker color than the recipient. These transplants do not change the somatic or germ-line genotype of the recipient or the kind of children they may subsequently produce.

14. Individuals do not evolve. An individual human zygote (fertilized egg) grows and differentiates into an embryo, fetus, baby, child, teen, adult, and senior citizen, and then dies. Even if a gene of an individual mutates in a somatic cell or a reproductive cell, the individual has not evolved. Populations of individuals may evolve. Evolution is said to occur if the frequency of a gene in the "gene pool" of a population changes from one generation to another.
15. An individual must survive to reproductive age before it can produce any offspring. An individual may live a hundred years but would have a fitness of zero if no progeny are produced.
16. This is an idea popularized by Charles Darwin. We now know that gametes do not contain preformed pieces of other body parts that simply become magnified by growth. The embryo develops epigenetically anew from the amorphous chemicals in the zygote using genetic instructions in its genotype.
17. Use or disuse of body parts does not change an individual's genotype. Neck lengths in a population of giraffes naturally vary from one individual to another. Ancestors with longer necks would have an advantage over those with relatively shorter necks in obtaining food during times of food scarcity and, thus, would be more likely to survive and reproduce offspring that are genetically predisposed to develop longer necks whether or not they stretched their own necks. By repetition of this process over many generations, natural selection produced the long necks typical of modern giraffes.
18. This statement is true because a natural population may contain matings between homozygous and/or heterozygous genotypes in various percentages, so that no fixed progeny ratios are to be expected.
19. Aside from the rare mutational deletion of a gene from a chromosome, no genes are normally "lost" during differentiation of various cell lineages. All normal human cells contain the hemoglobin gene, but this gene becomes epigenetically inactivated in all cells other than the lineage that differentiates into red blood cells.
20. Recessive alleles are normally only expressed in homozygous genotypes and thereby are hidden from phenotypic expression in heterozygotes. Dominant alleles cannot hide phenotypically from natural selection in heterozygotes; thus, their numbers can be more efficiently reduced in the population gene pool.

References

deVise, D. (2012). Some colleges looking beyond the lecture; Experts say method is too passive and recommend other teaching techniques. *Tribune* (San Luis Obispo, CA), 26 February, A5.

Levin, D.M., Grant, T. & Hammer, D. (2012). Attending and responding to student thinking in science. *American Biology Teacher*, *74*, 158–162.

McComas, W.F. (2012a). Darwin's invention: inheritance & the "mad dream" of pangenesis. *American Biology Teacher*, *74*, 86–91.

McComas, W.F. (2012b). Darwin's error: using the story of pangenesis to illustrate aspects of nature of science in the classroom. *American Biology Teacher*, *74*, 151–156.

Stansfield, W.D. (2011). Acquired traits revisited. *American Biology Teacher*, *73*, 86–89.

Stein, R.A. & Davis, D.L. (2012). Epigenetics: a fascinating field with profound research, clinical, & public health implications. *American Biology Teacher*, *74*, 213–216, 219–223.

Williams, M., Montgomery, B.L. & Manokore, V. (2012). From phenotype to genotype: exploring middle school students' understanding of genetic inheritance in a Web-based environment. *American Biology Teacher*, *74*, 35–40.

WILLIAM D. STANSFIELD is Emeritus Professor of Biological Sciences at California Polytechnic State University, San Luis Obispo, CA 93407. Mailing address: 653 Stanford Dr., San Luis Obispo, CA 93405-1123. E-mail: wstansfi@calpoly.edu.