A Survey to Evaluate Students' Understanding of Reproduction, Heredity, Ontogeny, and Phenotypic Diversity

Before beginning a series of presentations on heredity and evolution, it would be prudent to ascertain the general level of students' understanding of basic concepts in subjects such as reproduction, heredity, ontogeny, and mechanisms for generating phenotypic diversity, so that teachers will not waste time on well known subjects of general knowledge and can spend more time on subjects that are unknown or misunderstood by most students. Stern & Ben-Akiva (ABT February 2007) presented a lesson plan designed to challenge the commonly held naïve idea that acquired traits can be inherited. These authors present a couple of examples of acquired traits that are not heritable (mouse tail amputations and stretching giraffe's necks). However, I believe that a much more comprehensive set of statements for class discussion is needed to accurately indicate the breadth and depth of students' knowledge and/or misconceptions existing at any given level of a biology class.

List A (below) contains 33 statements that should give teachers an opportunity to better evaluate the level of understanding among pupils in their classes before proceeding with lessons in reproduction, heredity, ontogeny, and phenotypic diversity. Each statement is followed by a brief example response in parentheses, to which teachers may embellish or modify with their own knowledge. Each teacher may ask the class to respond to only selected statements most directly germane to the lessons that will immediately follow. The statements of choice may be individually presented by the teacher orally for class discussion, or they may be given as a hard copy homework assignment (List B, sans any responses) to be studied in preparation for the next class discussion. Perhaps students will be asked to respond in writing to specific List B statements using complete sentences or as short essays. Alternatively, the teacher may wish students to respond to statements in List B using a multiple choice format. A suggested way to record individual responses in this way follows List B as a separate sheet to be returned to the teacher for evaluation.

List A

1. The biological inheritance that we receive from our parents consists of all the substances and chemical systems present in the fertilized egg from which we developed. (Biological inheritance is more than genes. Genes cannot reproduce or be expressed without numerous enzymes, metabolic substrates, ribosomes, and other cellular structures.)

2. The only chemical system present at our birth that we, as adults, can transmit to our offspring consists of the nucleotide sequences in the DNA molecules of our chromosomes. (See explanation in item 1. Females also transmit their mitochondrial genes to all of their children. Epigenetic tags , such as methyl groups, on DNA may sometimes be transmitted from one or both parents to their offspring.)

3. Cancer-producing mutations that occur in the DNA of skin, lung, colon, prostate, or mammary tissues of parents can potentially be passed on to at least some of their children. (All body cells other than gametes (eggs and sperms) are called somatic cells. The notion that any parts of somatic cells, whether normal, cancerous or mutated, can be transmitted to offspring is wrong; see item 23.)

4. 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. (Some parents may have a genetic constitution that predisposes them to abusive behaviors. The misuse of these substances does not change their genes to become more easily addicted. They may then pass some of this genetic predisposition on to their children whether or not they 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 had a genetic predisposition to do so.)

5. People who get little or no physical exercise tend to become weak and are at risk of causing weakness in the muscular and bone development of their newborn children. (Body builders and athletes may tone their bodies to perfection, but none of the changes in their somatic cells will be transmitted to their offspring.)

6. Children of severely overweight parents might inherit the potential to become overweight, but would not inherit this tendency if their parents had dieted back to normal weight before conceiving children. (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 or excess weight than they would have if their food was not so readily available.)

7. If parents read profusely and work at retaining most of this knowledge, their children should be more likely to perform better on IQ tests (even if these children don't study as diligently as their parents and receive little or no tutoring from them) than if the parents had not studied so diligently. (All educators are not in agreement about exactly what biological attributes are reflected in IQ scores. It is highly likely that many aspects of brain activity are influenced by an individual's genotype, but environmental factors are very important too. Even if children are not tutored by their parents, they are exposed to the learning environment in schools. In homes where books are plentiful and parents regularly converse with each other about a wide range of subjects, children may be more likely to do better on IQ tests than those whose homes are not so intellectually enriched.)

8. Because a mother's egg cell is much larger than a father's sperm cell, most female children tend to be more mentally and/or emotionally like their mother than their father. (The mental abilities of boys and girls are influenced by genes from both parents. Sometimes children exhibit more mental abilities than either parent. It should not be surprising if girls tend to think and behave more like their mother than their father because girls are usually taught to play with dolls rather than with footballs. The hormonal system of girls is different than that of boys. Girls can find empathy with their physical and emotional experiences only in their mothers or other girls. The size of the parents' gametes has nothing to do with these affinities.)

9. The metabolism of food (energy utilization system) in boys is genetically programmed to be more like that of their fathers than that of their mothers. (The extraction of energy from food (catabolism) to form ATP molecules, and the subsequent use of ATP to build (anabolism) all other biological molecules of the body (proteins, lipids, carbohydrates, nucleic acids) is the same in both males and females. However, males tend to build

more muscle tissue than females, whereas females tend to deposit more fat in subcutaneous tissues than males, but exceptions are seen all around us.)

10. Fathers 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. (Both mothers and fathers contribute genes affecting 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 was 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 all foreign substances.)

11. People who have experienced emotionally/psychologically traumatic events (e.g., posttraumatic stress disorders) are more likely to have children with genetically based emotional or psychological problems than if those same parents had experienced no traumatic events, even if the children are reared from birth in foster homes. (If a person has a genotype that renders him/her more susceptible to stressful situations, they might be expected to transmit at least some of these kinds of genes to their children. However, this transmission could occur either with or without having experienced a traumatic event.)

12. People who move to very different environments (e.g., colder climate, new atmospheric allergens, increased population density, distance from contact with old friends, new job stresses, etc.), within one year before having children, will usually be more likely to have environmentally induced changes in their gametes (eggs, sperms) than if they had not moved. (As explained in item 11, stress does not induce changes in one's genotype, but stress may cause release of hormones that can have undesirable physiological effects such as impairing the immune system.)

13. People who have prayed diligently for their expected children are able to provide a better biological inheritance for them than if they had not prayed. (There is no scientific evidence that prayers of prospective parents can affect the genes that they transmit to their children. However, if women who pray are more likely to avoid alcohol, drugs, and smoking, they would provide a more healthy intrauterine environment for their children than if they had not avoided these harmful substances.)

14. 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. (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 a 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.)

15. 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. (Individuals do not evolve. An individual grows and differentiates into an embryo, fetus, baby, teen, adult, 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.)

16. By definition, long-lived individuals have greater "genetic fitness" than shorter-lived individuals of the same species. (The genetic fitness of an individual increases according to how many its offspring survives to reproduce. An individual may live a hundred years, but would have a fitness of zero if no progeny were produced. After women reach menopause, they are no longer able to produce children even if they wanted to and lived on many years after.)

17. If a cow gives birth to calf A sired by bull X, and a year later she gives birth to calf B sired by bull Z, the genetic constitutions of the cow and calf B might be contaminated to some extent by genes from bull X. ("Telegony" is an obsolete theory proposing that once a female is mated to a male, any subsequent offspring she produces sired by other males would tend to show characteristics of the sire that produced her first offspring. This seems to imply that the cow's first exposure to semen from bull X somehow donates one or more of his genes to her genotype, enabling them to be passed on to her subsequent offspring. This does not occur naturally in mammals.)

18. All children may inherit some different gene variants (alleles) from each parent, but (barring mutation) they normally receive exactly the same number of genes from each parent. (Females normally have two X chromosomes; males normally have one X and one Y chromosome. The Y chromosome is much smaller than the X chromosome and has many fewer genes. See item 30)

19. Genes that were expressed in a given cell type of a mother will, if inherited by children, be expressed in that same cell type of her children regardless of environmental variables. (Gene expression often depends on the environment and/or on the residual genotype. If the mother is homozygous for a recessive gene, her offspring might inherit a dominant gene from the father that would cause the child to express a dominant phenotype not present in the mother. Some genes in offspring may be active only if inherited from one or the other parent, a phenomenon known as "parental imprinting.")

20. When bacteria die and rupture, they release DNA fragments (sometimes containing whole genes) into their environment. These fragments may be taken up by living cells of the same species (sometimes of different species), become incorporated into their own DNA, and produce a new phenotype (trait). This process may be thought of as "the inheritance of acquired characters." (Yes, if one accepts that IAC is generally defined as the appearance of a new heritable trait (capable of being transmitted to offspring) in an organism as a consequence of its exposure to an environmental stimulus (physical or chemical).)

21. All viruses must infect cells to reproduce. The reproduction of some viruses (retroviruses) requires that their genetic material (RNA) becomes copied into DNA and incorporated into the DNA of their host cells. Thus, the genetic composition of such cells becomes modified by the acquisition of new genes derived from their environment. (This statement is true. The human HIV virus is one kind of retrovirus that reproduces in this way. The human genome is littered with remnants of defunct retroviruses from our ancestors.)

22. It has been scientifically proven in multiple species that specific adaptive gene responses can be turned on or off depending on the kind of food (e.g., sugars) or other environmental variables available to them.(This statement is true. For example, a bacterium normally may not produce the enzyme lactase unless it is stimulated to do so by the presence of lactose sugar in its environment. This is an adaptive response that prevents wasting energy in the production of the enzyme for which no substrate is present.)

23. At sexual maturity, small pieces of adult animal tissues (called gemules) from different parts of the body (e.g., head, torso, arms, legs, liver, lungs, heart) are transported by the blood stream to the gonads (ovaries and testes) and there become incorporated into gametes (eggs and sperms) during their formation. These gemules become amplified as the embryo grows to regenerate the same general kind of body parts from which they were derived. (This is an old 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.)

24. The distant ancestors of modern sea otters lived on land. When food was scarce, they needed to find new sources of food. Some of them began searching for food on the sea floor. This required them to swim, dive, and hold their breath underwater. Such voluntary actions, in response to specific needs, caused hereditary changes to occur in their inborn nature, such that their offspring inherited a slightly better ability to swim (e.g., foot webbing) and to hold their breath longer. As this process was repeated in each generation, the otters gradually became better able to exploit their aquatic environment and thereby increased their chances of survival. Thus, the modern concept of the way that adaptive evolutionary changes generally occur can be summarized as follows: needs → actions → adaptive hereditary cellular modifications → improved body functions → increased offspring survival rates. (This concept is wrong for the same reason that the giraffe’s neck did not become longer because ancestors voluntarily stretched their necks to get food high in trees. Long necks evolved because in times of food scarcity, ancestors that happened to have longer necks were better able to survive and reproduce than other members of the population with shorter necks.)

25. The sex of individuals in some species (such as alligators and some lizards) is not determined by X and Y chromosomes, but by the environment (e.g., temperature) in which they are reared. (This is true and it demonstrates the dramatic influence that some aspects of the physical environment can sometimes have on the development of body parts. The animal’s genotype does not change in response to temperature changes.)

26. In some animal species (e.g., bees), males develop from unfertilized eggs. (True. This process is termed “parthenogenesis.” All sperm cells of a drone bee are produced mitotically rather than meiotically and hence are all genetically identical. Female bees develop from fertilized eggs (diploid). Female worker bees are prevented from becoming fertile as long as a queen bee is in the hive producing her pheromone. New queens develop from fertilized eggs that are fed a special food called “royal jelly.” Thus, female fertility vs.sterility is dependent upon the nutrition the diploid larvae receive.)

27. As an animal embryo develops from a fertilized egg, various cells lose different genes, causing them to differentiate into specific cell types (e.g., muscle, skin, bone, blood, etc.). For example, the only cell type that makes hemoglobin is the red blood cell (erythrocyte) because it alone retains the genes that code for hemoglobin that were lost in the differentiation of other cell types. (Barring mutation, every diploid cell of an organism contains the same set of chromosomes and the same genetic content. There is no gain or loss of chromosomes or genes during differentiation. Rather, different sets of genes are turned on or off in various cell lineages to give each organ and body part its characteristic anatomical and physiological attributes. Every normal cell of the animal body contains the gene for hemoglobin, but the gene is only expressed (active) in erythrocytes.)

28. The only cells of an adult organism that contain the full set of genes in the fertilized egg from which it developed are the germ-line cells of its gonads (ovaries or testes) that have the ability to produce gametes (eggs or sperms, respectively). (This is false; see explanation for item 27.)

29. Egg cells carry only a sample half of the nuclear genes that are present in other cells of a female’s body. (True. Meiosis reduces the diploid chromosome number to the haploid number in gametes.)

30. Both boy and girl babies normally inherit some genes exclusively from only one of their parents. (Boy and girl babies normally inherit their mitochondrial genes only from their mother. Boys inherit their Y chromosome only from their father,)

31. If the frequency of a trait in a population changes from one generation to the next, this necessitates evolutionary genetic changes in the gene pool. (In item 22, the production of lactase enzyme was said to occur only if lactose sugar was present in the environment. So, it would be possible for the frequency of lactase production in a population of bacteria to go from 100% in one generation to zero percent in the next, depending on the presence or absence of lactose in their environment without any change in the gene pool of the population.)

32. If a woman’s blood type is Rh-negative and she gives birth to an Rh-positive child of either sex by man X, it is possible that the survival of each of her subsequent Rh-positive children may be jeopardized whether their father was X or some other man. These facts exemplify the phenomenon called “telegony,” i.e., that a female’s heredity can be so changed by her first conception that her subsequent children may be affected even if they are sired by other males. (Telegony was described in item 17. Some blood cells of an Rh-positive baby can enter the maternal circulation, causing her to make antibodies to the foreign Rh antigen. These antibodies may attack the red blood cells of the baby, causing a disease known as “erthroblastosis fetalis” or “hemolytic disease of the newborn.” Some of these antibodies may still be in the maternal circulation when she is carrying a second Rh-positive child (whether fathered by the same man or another man). That

child could then come under immune attack while in the uterus from maternal antibodies. However, this phenomenon is due to a physiological change in the mother (production of anti-Rh antibodies), not due to a change in the mother's genotype.)

33. Varieties of wheat that are normally planted in the autumn require a prolonged cold spell during winter in order for them to be capable of flowering the next spring, a process called "vernalization." Varieties of wheat planted in the spring do not require cold treatment to flower. The heredity of winter wheat can be changed to that of spring wheat if provided the proper pre-planting environment. (This was a claim of the Russian agronomist T.D. Lysenko who ruined the science of genetics from about 1930 to 1960. He soaked winter wheat seeds in water to stimulate germination, and then suspended their growth in a snow bank until spring. When planted in the spring, the germinated seeds had a week or two head start on spring wheat that had not started to germinate until planted. Lysenko called this process "vernalization." Neither germinating seeds before planting nor subjecting seeds to cold treatment changes the heredity of the treated seeds.)