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Oh, Behave! Behavior as an Interaction between Genes & the Environment

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Abstract

This lesson is designed to teach students that behavior is a trait shaped by both genes and the environment. Students will read a scientific paper, discuss and generate predictions based on the ideas and data therein, and model the relationships between genes, the environment, and behavior. The lesson is targeted to meet the educational goals of undergraduate introductory biology, evolution, and animal behavior courses, but it is also suitable for advanced high school biology students. This lesson meets the criteria for the Next Generation Science Standard HS-LS4, Biological Evolution: Unity and Diversity (NGSS Lead States, 2013).

Key Words: *Behavior; sociality; evolution; traits; genes; environment.*

Introduction

Students hold many preconceptions about behavior and how it functions (Vaughan, 1977). Social behavior, in particular, is often misunderstood as being solely environmental or solely learned, in part because of cultural biases that separate human behavior from animal behavior (Ridley, 2003). These ideas are embodied by the "nature vs. nurture" controversy, in which behavior is often thought to be either genetically controlled or determined by the external environment (Reece et al., 2010). Students struggling with the effects of genes often have the misconception that those effects are completely independent of the environment (Sternberg & Grigorenko, 1999), which may be derived, in part, from how students understand heritability (Visscher et al., 2006; Wray & Visscher, 2008). However, these characterizations ignore the complex interplay between genetics and the environment that underlies all behavior. Thus, it is critical that students grasp that genes and the environment work together to affect behavior. Evolution is influenced both by genes and by the environment and is the foundational framework of biology (Dobzhansky, 1973), yet students struggle with evolution at all levels (Bishop & Anderson, 1990; Nehm & Reilly, 2007; Gregory, 2009; Opfer et al., 2012). The goal of this lesson is for students to model complex behaviors as a dynamic system in which genes and the environment interact. The lesson illustrates that differences in behavior produce variation in survival, resource acquisition, and reproduction, leading to evolution. Reece et al. (2010) provide suitable background information for teachers conducting this lesson, particularly chapters on behavioral biology and evolution.

Methods

We utilize cooperative learning methods to engage students in critical thinking. Such active, inquiry-based learning has been shown to be more effective than passive learning techniques, such as lecture (Prince, 2004; Michael, 2006; Derting & Ebert-May, 2010). We developed this lesson using backward design (Wiggins & McTighe, 2006) centered on the 5E learning cycle of engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 1989) to engage students in activities focused on desired learning outcomes. These methods will enable students to use real scientific evidence to evaluate their biases and misconceptions about genetics, behavior, and evolution.

We start by having students confront their prior knowledge regarding the genetic and environmental basis of behavior, using data from published scientific papers. Students then construct models that demonstrate that behavior, like other traits, is controlled both by genes and by the environment, using the framework provided by Robinson et al. (2008). Students finish by generating hypotheses and predictions about data to link the seemingly disparate concepts of genes and environment together into a more complex model of behavioral function and evolution.

Learning Goals

- Apply knowledge gained from reading a scientific paper to connect biological concepts of traits, population, genes, behavior, selection, variation, evolution, fitness, plasticity, and environment.
- Make predictions about how the environment and genetics interact to form behaviors.
- Interpret graphs and use data to reevaluate predictions on the interaction of environments and genes in determining behavior.
- Model evolutionary relationships between behaviors and genes.
- Apply concepts from the lesson in order to make predictions about evolutionary outcomes.

Instructional Strategy

Engagement

At the end of the class period preceding this lesson, take an informal poll to assess students' preconceptions about behavior and genetics, asking what proportion of a given behavior they believe is controlled by genetics as opposed to learned. To prepare for the next class session, assign Robinson et al. (2008) for homework. That study describes genes and regulatory sequences that help produce behavior and how evolutionary changes in the genome influence behavior. Additionally, ask students to record any unfamiliar terms as they read and define them in the context of the paper. These terms will help students form a conceptual understanding and facilitate discussion in the next class period.

At the next class meeting, students will share definition lists in a think–pair–share activity to ensure that the reading was completed and to give students the opportunity to compare and correct their lists with others. The definition lists will be used and revised during the course of the lesson to facilitate discussion and make clarifications when necessary.

Exploration (20 minutes)

At the beginning of the class period, students will be assigned to groups of three or four. Each group will be asked to model the steps between social experience, genes, and behavior for one of the following examples from Robinson et al. (2008: fig. 1): mating preference in prairie voles, mothering style in rats, treatment of queens by fire ants, song recognition in zebra finches, male dominance in cichlids, and courtship communication in fruit flies. The models should be formatted following the steps shown in vector A or vector B (Figure 1). Examples of suitable responses for both vectors are shown in Figure 2, using information on honeybee foraging drawn from Robinson et al. (2008). Students will construct their model on a whiteboard, using terms from their lists, and present to the class after 10 minutes of group discussion. The class will then devote ~10 minutes to discussing the group-developed models.

Explanation (10 minutes)

The instructor will then conduct a mini-lecture on the basic principles the students have been modeling. Vector A illustrates the phenomenon of environmental plasticity. Plasticity is the ability of a single genotype to produce multiple phenotypes when exposed to environmental conditions. Plasticity allows an organism to respond

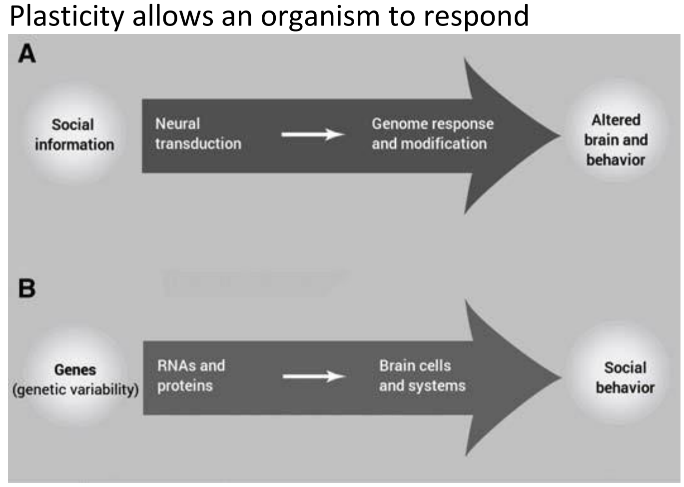

Figure 1. (A) From social information to changes in brain function and behavior. Social information is perceived by sensory systems and transduced into responses in the brain. Social information leads to developmental influences often mediated by parental care, as well as acute changes in gene expression that cause diverse effects (e.g., changes in metabolic states, synaptic connections, and transcriptional networks). Social information also can cause epigenetic modifications in the genome. Variation in both environment (V_E) and genotype (V_G) influences how social information is received and transduced and how these factors themselves interact ($V_E \times V_G$). (B) From genes to social behavior. Genes influence the social behavior of an individual through their effects on brain development and physiology. This linkage is sensitive to both genetic (V_G) and environmental (V_E) variation and to their interactions ($V_G \times V_E$). From Robinson, G.E., Fernald, R.D. & Clayton, D.F. (2008). Genes and social behavior. *Science, 322,* 896–900. Reprinted with permission from AAAS.

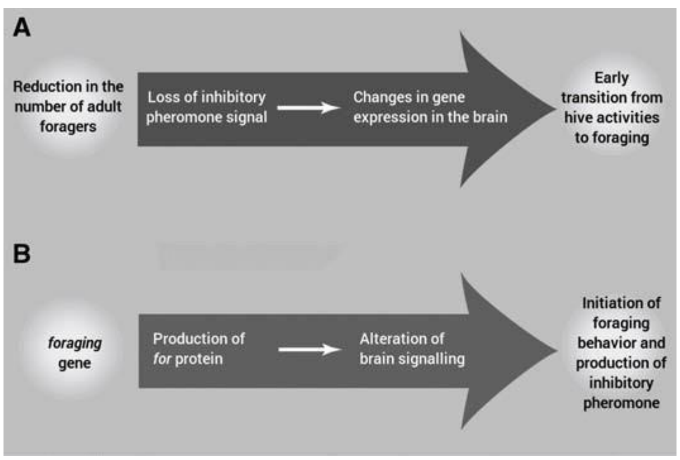

Figure 2. An example of the model that students should create based on the processes depicted in Figure 1, using the honeybee example. Adapted from Robinson, G.E., Fernald, R.D. & Clayton, D.F. (2008). Genes and social behavior. *Science, 322,* 896–900. Used with permission from AAAS.

to variability in the environment in potentially adaptive ways. Vector B illustrates genetic variation. Differences in genetic sequence or expression pattern among individuals can cause differences in behavior.

These differences in behavior cause variation in survival, resource acquisition, or reproductive success among individuals in a population. Through the process of natural selection, individuals with the highest fitness contribute more offspring to subsequent generations, and the population evolves. Plasticity itself can be considered a trait and has a genetic basis, so the interactions illustrated by vector A are also subject to natural selection and evolution.

Elaboration (20 minutes)

The instructor will then present students with a novel example of behavioral data (Figure 3) to analyze. We suggest that students view data from Kozak et al. (2011), in which imprinting influences mate choice in two closely related stickleback species. If desired, this lesson can be adapted using other data, but it is most effective if behavior examples are simple to read and the environmental or genetic components are known.

In this example, the class is presented with pictorial descriptions of the mating systems in the two species of stickleback fish. The first two slides show that female stickleback sexually imprint on their father's species during rearing and, if swapped with a "foster" father, will sexually imprint on the foster father's species on the basis of his species-determined odor. Simply, a female learns a father's odor and preferentially mates with males of that species.

Ask each student to individually predict and record the mating preference of females for the following situations: females reared with a conspecific father, a heterospecific father, heterospecific odor only, and no father/odor. After 5 minutes, let groups discuss and reach a consensus on their predictions. Be sure to walk around and answer questions, but do not give solutions. After group discussion, select a student to record answers on the board, and ask two or three groups to offer solutions; ask if any groups have a response that differs from those written on the board. Accuracy is not important at this stage. The key is to get the students thinking about the interaction between the paternal environment and genetic determination.

Next, show students the actual data from the scientific study (Figure 3). Give the students 5 minutes to discuss the data shown and to revise their predictions if necessary. Ask for two or three groups to share how they interpreted the data and why they think the behavior (imprinting on mate choice) might be subject to both environmental and genetic components (*What other factors might be at work? Can this trait evolve?*). Reveal additional data supporting both genetic and environmental components. We suggest revealing that genes for male nuptial coloration (redness) strongly predict mate preference, as do the species-specific behaviors that

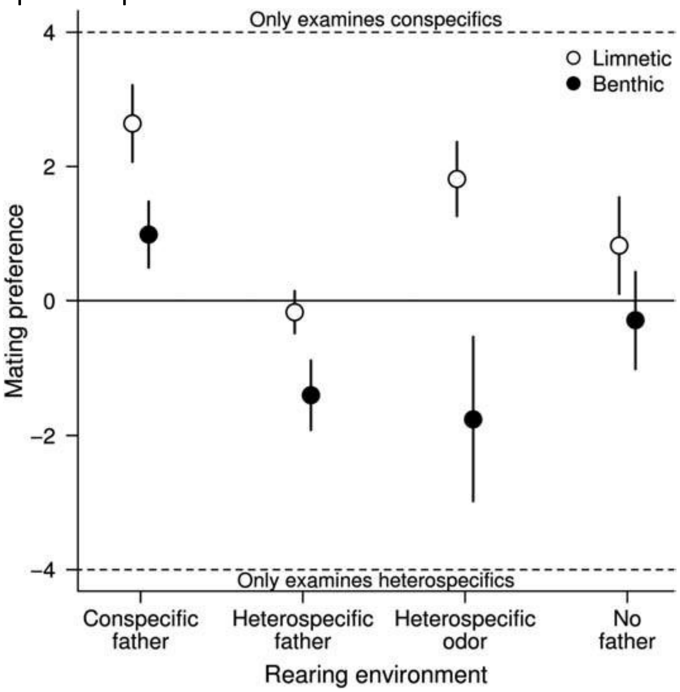

Figure 3. Effect of paternal exposure on mating preference of limnetic (open circles) and benthic (filled circles) stickleback females. Symbols are mean estimates ± SE. Solid line indicates equal probability of conspecific and heterospecific examination. Dotted lines are estimates of the level at which only conspecific (positive) or heterospecific (negative) males would be examined. Adapted with permission from Kozak, G.M., Head, M.L. & Boughman, J.W. (2011) Sexual imprinting on ecologically divergent traits leads to sexual isolation in sticklebacks. *Proceedings of the Royal Society of London Series B, 278,* 2604–2610.

males perform in courting females. At the end of this period, collect the students' predictions, revised group predictions, and explanations for why the example behavior given has both genetic and behavioral components.

Evaluation

Students will turn in a copy (e.g., carbonless paper) of their definitions from the reading and any revisions or additions made at the end of class. For the final assessment, students will be expected to write detailed models, for both vector A and vector B (modeled after Figure 2), of imprinting in stickleback mating (or the example used). Students should use key terms, including (but not limited to) *variation*, *trait*, *gene*, *plasticity*, *fitness*, *selection*, *mate choice*, *population*, *evolution*, *environment*, and *behavior*. Students should show the relationship between the imprinting system in stickleback and these terms and be able to generate predictions from their model about father odor and female mate choice at adulthood.

Extensions

This lesson can be expanded by asking students to predict evolutionary outcomes under changing environmental or demographic conditions. For example, what mating strategies should females adopt when "ideal" males are plentiful (or rare), and what would the evolutionary consequences be of accepting a male with the wrong odor trait? Students should be given time to construct models, make predictions, and provide a rationale to hand in at the beginning of the next class period.

Conclusion

By the end of this lesson, students will have practiced confronting and revising their prior knowledge using evidence and will have made predictions about evolutionary outcomes of behavioral variation. Most importantly, students will have constructed models that demonstrate that behavior, like other traits, is influenced by both genes and the environment and can contribute to the evolution of species.

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Appendix 1. Exercise rubric.

Criteria	1 Unacceptable	2 Acceptable	3 Good/Solid	4 Exemplary
Elements/Terms of the Model	Terms in the model are unclear, inappropriate, and/or have significant overlap in use (e.g., *change* used to mean both "adapt" and "evolve")	Terms included can be identified conceptually, are not clearly differentiated, or are inappropriate	Terms included are clear, appropriate, and distinct. Effort was used to include specific scientific terms and/or clear explanations	The model correctly uses or identifies examples of many of the following terms: variation, trait, genes, plasticity, fitness, selection, mate choice, population, evolution, environment, generation, behavior
Distinction between Concepts	Little or no distinction can be made between concepts	Some concepts are described well	Distinctions between most concepts are clear	Each concept is distinct and clearly differentiated
Connections between Concepts	Concepts are not at all connected	Some concepts are correctly connected, but key connections are lacking	Most concepts are correctly connected and/or some key connections are provided	Key connections are present and serve as a framework for other ancillary connections
Concept of Behavioral Traits	Model neglects mentioning any of the following: behaviors are traits, have a genetic component, and can be shaped by evolution	Model identifies only one of the following: behaviors are traits, have a genetic component, and can be shaped by evolution	Model identifies two of the following: behaviors are traits, have a genetic component, and can be shaped by evolution	Model identifies that behaviors are traits, have a genetic (and sometimes a plastic) component, and can be shaped by evolution
Concept of Fitness	Model neglects mentioning any of the following: genes and plasticity determine traits, selection acts on traits to produce variation in fitness, some traits are more fit than others	Model identifies only one of the following: genes and plasticity determine traits, selection acts on traits to produce variation in fitness, some traits are more fit than others	Model identifies two of the following: genes and plasticity determine traits, selection acts on traits to produce variation in fitness, some traits are more fit than others	Model identifies that genes and plasticity determine traits, selection acts on traits to produce variation in fitness, and some traits are more fit than others
Concept of Evolution	Model neglects mentioning any of the following: that evolution happens at the population/species level, is a change over generational time, is linked to genetic changes in the population	Model identifies only one of the following: that evolution happens at the population or species level, is a change over generational time, is linked to genetic changes in the population	Model identifies two of the following: that evolution happens at the population or species level, is a change over generational time, is linked to genetic changes in the population	Model identifies that evolution happens at the population or species level, is a change over generational time, and is linked to genetic changes in the population
Logic of Predictions Based on Models	Model is incomplete or its logic, even if flawed, is not clear enough to identify whether predictions follow model	Logic is present in the model, but it is incorrect	Most logical connections are drawn, but predictions (outcomes) of model are unclear or incomplete	Logical connections are drawn, and predictions (outcomes) of model logically follow and are correct
Scoring:	0–10 = needs improvement	10–15 = workable	16–20 = solid/good	21–24 = exemplary

Appendix 2. Example answer (in paragraph form).

In the **population**, **variation** exists in both the extent of **plasticity** and the **genes** that encode male odor, a **trait** females use in **mate choice**. Females search for and select males whose odor matches that of their father. This **behavior** by females is influenced by the **environment**, which may contain many or few males with which the female can mate. Because females **select** the odor that matches the father's species, females will have higher **fitness** if they correctly choose a male of their own species and avoid having less-fit hybrid offspring, which are **selected** against in the **environment**. These females that survive and produce more-fit offspring then pass on genes for correctly selecting a mate on the basis of odor to the next **generation**. Over many generations, females repeatedly choosing males of their own species by using odor has been a form of **selection** that reinforced the **evolution** of these species, based on adaptation to their environments (top or bottom of the lake).