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The Natural Selection Game: Incorporating Active Learning in Evolution Curricula for General Biology

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Abstract

Teaching evolution in high school and in entry-level college courses can be challenging due to the inherent misinformation, misunderstanding, and biases with which students approach the topic. In this setting, it is critical to both teach the basic concepts and address common student misconceptions about evolution. We present two paired activities that allow students to (1) explore the processes of natural selection in a direct and experiential way and (2) address common misconceptions in evolutionary theory. The first activity, the "Natural Selection Game," has students simulate a bird population and experience shifts in phenotype frequency as a result of selective pressures. Following the end of the game, students discuss the outcomes and connect them to real-life examples. The second activity encourages students to actively research common misconceptions with the use of personal technology in order to distinguish between scientifically supported data and poor information online. Both activities can be incorporated in high school and university-level general biology curricula. They will allow students to connect their firsthand experiences to lecture-based instruction and, as a result, develop a stronger understanding of the mechanisms of evolution.

Key Words: *evolution; natural selection; active learning; biology curriculum; pedagogy; hands-on game.*

○ Introduction

For science educators tasked with teaching evolution at the high school or university level, presenting evolution as a coherent and unifying principle of biology has faced a wide array of challenges and missteps over past decades (reviewed in Alters & Nelson, 2002; Rutledge & Mitchell, 2002; Friedrichsen et al., 2016). Traditional pedagogical approaches have involved instructor-centered teaching in which information is presented to students with the expectation that it will simply be transferred and in which misconceptions about topics are often left unaddressed (Alters & Nelson, 2002). This approach favors students who can figure out how to retain the information necessary while leaving the rest to flounder. The advent of the *Next Generation Science Standards* (NGSS) in

Science, Technology, Engineering, and Math (STEM) has tackled this issue by sparking a nationwide movement toward more student-centered pedagogical approaches (Achieve Inc., 2013). With this new trend, many teachers and institutes have strived to incorporate more active-learning techniques in classroom curricula (Grooms et al., 2015; Friedrichsen et al., 2016; Odom et al., 2017; Puttick & Drayton, 2017). As a result, much progress has been made toward reforming teaching practices in biology through the development and publication of active-learning strategies for teaching core concepts (see, e.g., Lauren et al., 2016; Odom et al., 2017; Rowland et al., 2017; Kane et al., 2018). We hereby contribute to these strategies with a fun and engaging improvement to a classic activity for teaching natural selection.

It can often be difficult for students to fully grasp the complex mechanisms of evolution, as it requires the ability to think scientifically (Crawford et al., 2005). Students typically view academic knowledge dichotomously as either right or wrong, and they tend to passively accept information rather than analyze evidence that contradicts misconceptions (Alters & Nelson, 2002). In order to encourage critical thinking, instructors should engage students in activities that lead them to discover facts on their own, rather than provide the facts for them (Snyder & Snyder, 2008). The challenges of teaching evolution can be particularly severe in nonmajors and general biology courses in which students have limited background in necessary biological concepts, and where time allocated to the discussion of evolution may be limited. However, one study has shown that even students who majored in biology scored only slightly better than nonmajors on the topics of ecology and evolutionary biology (Sundberg & Dini, 1993).

Further exacerbating the challenge of teaching evolution are opposing religious views and religious organizations that have actively stigmatized the topic for students in the United States and abroad (Lawson & Weser, 1990; Alters & Alters, 2001; Antolin & Herbers, 2001; Tidon & Lewontin, 2004). The most recent Pew Research Center report on the issue indicated that, on average, 31% of Americans did not believe that humans evolved over time,

and 29% did not believe that scientists agreed on evolution (Funk & Rainie, 2015). Furthermore, surveys of student conceptions of evolution have revealed the persistence of recurring misconceptions, which pose a major impediment to grasping evolutionary theory if left unaddressed in the classroom (Bishop & Anderson, 1990; Demastes et al., 1995; Alters & Nelson, 2002).

Ultimately, the solution to improving public understanding of evolution converges on teaching approaches. Conveying a solid understanding of the mechanisms of complex concepts in a manner that incorporates team-based learning and simulation models has been shown to be successful in the classroom setting (Zacharia, 2005; Grisé et al., 2011). This method allows students to explore and discover concepts through their experience, and positions them to better understand the associated facts presented by the instructor as a follow-up. Furthermore, having students address common misconceptions in an active manner is vital to guiding them toward a more complete and informed position when teaching valuable and potentially contentious topics (Nelson, 2008). This strategy encourages students to be open to exploring misinformation that may already be part of their personal understanding of the topic, and helps instructors facilitate the learning of potentially sensitive topics without outright student rejection (Smith, 1994; Nelson, 2008). For these reasons combined, it is imperative to conceptualize and present innovative and novel learning strategies that are effective in conveying a comprehensive understanding of evolution, as we have done here.

○ Examples of Natural Selection

Classic examples of natural selection often involve populations of organisms that experience phenotypic variation shifts toward one end of an extreme (i.e., directional selection) as a result of an environmental change (Grant & Grant, 2002; Brodie et al., 2005; Cook & Saccheri, 2013; Mills et al., 2018). Examples of natural selection that encompass both the microevolutionary and macroevolutionary scales are ideal for incorporating into evolution curricula. For example, Hoekstra et al. (2006) demonstrated that a single nucleotide mutation in the melanocortin-1 receptor gene (*Mc1r*) of beach mice was responsible for a malfunction of the melanocortin-1 protein, which results in lighter fur pigmentation. The codominant nature of both mutated and wild-type *Mc1r* alleles resulted in a spectrum of fur color, and the prevalence of a specific fur color in an individual population reflected habitat substrate (Mullen et al., 2009). Allelic frequencies of fur colors that matched the habitat's substrate were higher than those that did not, because individuals with fur colors that provided the best camouflage were more likely to survive against visual predators (Hoekstra et al., 2004; Mullen & Hoekstra, 2008). A similar example of natural selection involves the recent rapid evolution of mammals that undergo a seasonal fur color molt from summer brown to winter white (Jones et al., 2018; Mills et al., 2018). In this case, shortening winter periods have caused lowered fitness for winter white individuals that inhabit increasingly snowless environments as a result of anthropogenic climate change (Mills et al., 2018). These examples demonstrate how environmental changes can cause shifts in allele frequencies based on individuals' ability to avoid predation. Alternatively, the evolution of Darwin's finches presents classic examples of how environmental changes can cause shifts in population allele frequencies based on individuals' abilities to exploit food resources (Grant & Grant, 2002). For example, a reduction in the number of seed-producing plants resulting from a severe drought in 2004–2005 caused medium ground finches (*Geospiza fortis*) with larger beaks to die off, while individuals with smaller beaks survived because they were able to exploit a wider variety of seeds (Lamichhaney et al., 2016). The genetic source of Darwin's finch beak size was recently traced to the *HMGA2* gene, which occurs as a codominant allele, although the exact pathway by which the gene controls beak size has yet to be elucidated (Lamichhaney et al., 2016). These examples are just a few of the many real-world cases of natural selection that can be used to relate to the experiences the students gain after participating in our natural selection simulation. The "Natural Selection Game" we present here can be directly related to the Darwin's finch system. This activity builds on a classic active-learning strategy that exists in various forms of teaching resources (Walker, 2003; Roehl et al., 2013). Although this activity is not novel, it improves on previous models by incorporating a genetic inheritance component and addressing parasite load to more accurately simulate natural selection.

○ Game Overview

In the Natural Selection Game, students simulate a population of birds with two beak shapes. Their beaks determine how efficient they are at collecting their primary food source, which consists of two types of insects. Throughout the game, students compete with each other over food resources, and as a result we see the phenotypic variation of the population shift toward one end of the spectrum or the other, depending on what "insect" is most prevalent as their food source. Following the game, students discuss the connections between what they experienced in the game and the mechanisms of evolution, through a guided series of questions and a presentation of real-life examples from the instructor.

We suggest having students participate in the game, discuss the results through a series of questions, relate them to real-world examples such as those addressed above, and then address misconceptions following the game. This arrangement allows students to first explore and experience the principles of natural selection, then connect their experiences from the simulation with the proper vocabulary and facts for these processes. Following these activities, students will be ready to actively address misconceptions about evolution through the group activity we describe following the Natural Selection Game.

The objective of the game is to immerse students in a simulation that allows them to experience natural selection by actively participating in the "struggle to survive." The game is designed to fit into a general biology curriculum as the introductory segment of a lecture series that introduces key concepts and misconceptions of evolution and discusses the mechanisms of natural selection and speciation (e.g., gene flow, vicariance). It is meant to follow lectures covering genetics. The goal of the game is to guide students to discover the concepts of evolution on their own through an active learning experience. An outline of the game is presented in Table 1. This activity meets *Next Generation Science Standards* MS-LS2-1, MS-LS2-4, MS-LS2-5, MS-LS4-4, MS-LS4-6, HS-LS4-2, and HS-LS4-5.

Table 1. A general overview of game play for the "Natural Selection Game."

Step 1	Students are assigned one of two beak phenotypes (spoon or chopsticks) and the associated genotype (two beak shape alleles).
Step 2	Students use their "beaks" to feed on two types of "insects," one of which is more plentiful than the other.
Step 3	Students who feed on enough "insects" survive to reproduction and pair up with another successful student to tag in two additional students who randomly receive one beak allele from each "parent" genotype.
Step 4	The game continues for several rounds and students with the most efficient beak phenotype "reproduce" more frequently.
Step 5	The game is interrupted by a simulated natural disaster, which shifts the food availability.
Step 6	Students resume the game and should find that the alternate beak phenotype becomes more efficient, and the population shifts toward the alternate beak phenotype.
Step 7	Students break up into groups and are tasked with answering questions that help connect their experiences in the game with real-world parallels.

Materials

- Several packs of gummy worms (amount will vary based on number of students participating)

- Several packs of low-friction, relatively round candy (amount will vary based on number of students participating; it is important that the candy be easier to pick up with a spoon than with chopsticks)

- A stack of clean paper

- A handful of coins (~20 coins should be more than sufficient)

- ~30 pairs of chopsticks (amount will vary based on number of students participating)

- ~30 spoons (amount will vary based on number of students participating)

- Access to one or more large tables, around which students can gather

Game Setup

On a large table, lay out clean paper to cover the center of the table (Figure 1A). Around the edge of the table, set up as many individual sheets of paper as can fit (Figure 1A). The paper covering the center of the table represents the substrate in which the food source (i.e., candy) of the birds is found. The amount of candy placed on the table will depend on the number of students participating in the game and should be estimated by the instructor. The two types of candy represent different types of insects that are available as a food source for the birds in this given hypothetical population. Gummy worms represent worms, while round candy represents beetles. For the first few rounds of the game, worms are the dominant food source and therefore more gummy worms should be made available on the table than round candy. Each student in the first round of the game receives an individual sheet of paper that represents their stomach content and that indicates their beak genotype. Before the start of the class, pre-designate the genotypes "B, b" on the paper by writing them on the top corners of each

sheet (see instructions in Figure 2). Only students who start the first round of the game will have their genotypes pre-designated. The students who join in later through "reproduction" will use a coin toss to determine which alleles they will inherit (Figure 2). The sheets of paper for each student participating in the game should be placed along the edge of the table. Each student in the game will act as an individual bird, and their sheet of paper will represent their stomach contents. Once a student is out of the game, they will remove their sheet of paper from the table.

On the center of the table, spread out the candy so that ~60% consists of gummy worms and ~40% consists of round candy (Figure 1B). The gummy worms represent worms, and the round candy represents beetles. In the first few rounds of the game, the most abundant food source is worms. We recommend that the setup described above be completed prior to the start of class to ensure a smooth transition into the game once that point is reached during class.

At the start of the game, select ~12 student volunteers. The number of student participants can be modified as needed, depending on class size and space constraints. We are describing a method that has worked in class sizes of 200 or more students. However, with a smaller class it is possible to have all students participate by setting up two tables and dividing the class in half. Assign genotypes and phenotypes as described in Figure 2. The chopsticks and spoons represent two beak-shape phenotypes that exist in a population of birds and that are expressed by dominant-recessive alleles. The students represent the birds.

Playing the Game

Have the students gather around the table and ensure that each has their designated "stomach" (i.e., sheet of paper). Set a timer for 10 seconds. In that time the students will need to gather as many "insects" into their stomachs as they are able. If they are able to collect at least five, they get to "reproduce" by pairing with another successful student and tagging in two additional students as their offspring. When students "reproduce," they toss a coin to determine which of their two alleles they pass down to their
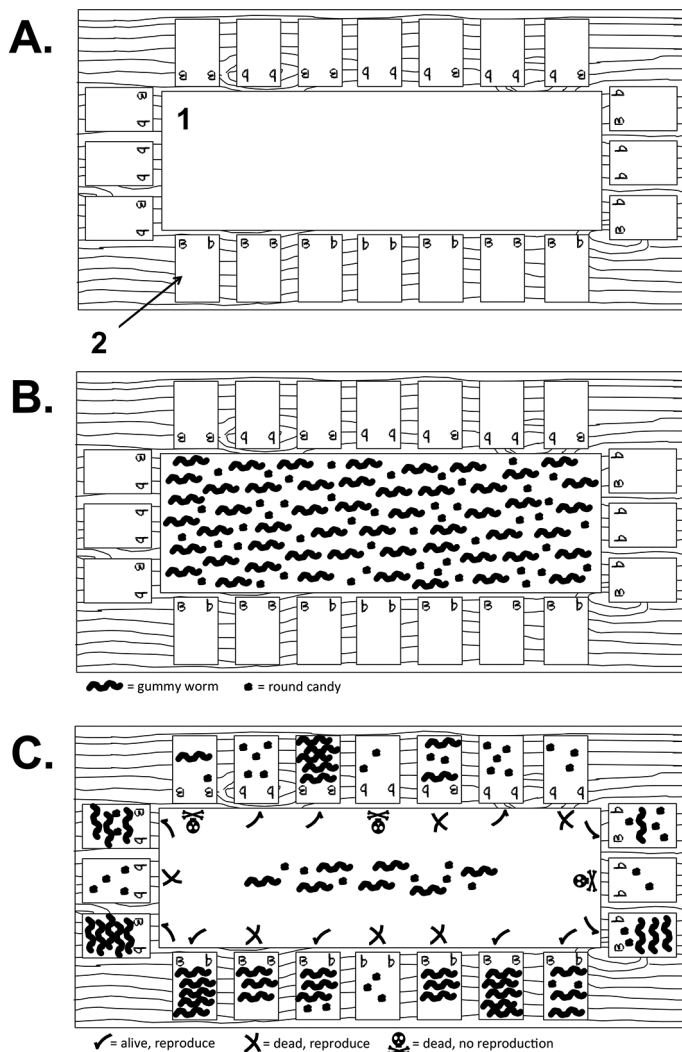
Figure 1. Diagram illustrating (**A, B**) game setup and (**C**) game play. The center space of the table represents the area in which the food source (i.e., gummy worms and round candy) for the birds will be placed, while the edge of the table is lined with participating students' sheets of paper, each representing the stomach content of an individual bird. An example of the game-play table following one round (**C**) shows that individuals who are able to collect at least five food items in their stomach contents both "reproduce" and survive to the next round (indicated by a check mark). Individuals who are able to collect at least three food items in their stomach contents "reproduce" but do not survive to the next round (indicated by an X mark). Individuals who are not able to collect at least three food items neither "reproduce" nor survive to the next round (indicated by a skull mark).

offspring (one coin toss per offspring). If the parent flips a coin heads up, then the offspring will receive the allele on the top-left side of the parent's sheet of paper; if the coin lands tails up, then the offspring will receive the allele on the top-right side of the parent's paper. The side of the paper on which the offspring assigns their inherited alleles is randomly chosen by the offspring (i.e., they will write their two inherited alleles on the top corners of a blank sheet of paper once they determine which alleles they will get from
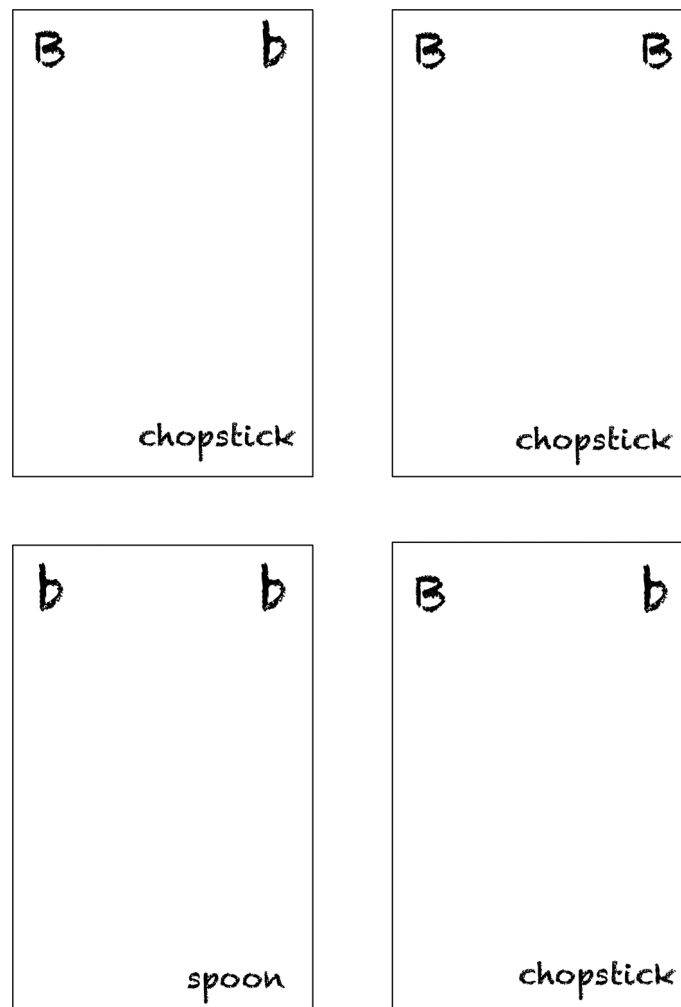

Figure 2. Example of sheets of paper assigned to students participating in the game's first round. Approximately 75% of the students in the first round should be assigned the dominant chopstick beak phenotype, and approximately 75% of those students should be assigned heterozygous genotypes (Bb), while the remaining 25% should be assigned homozygous genotypes (BB). The students who are assigned the recessive spoon phenotype should all be given the other homozygous genotype (bb).

each parent). Finally, each time a student produces an offspring, they will make a check mark on their sheet. At the conclusion of the game, the student who has produced the highest number of offspring will win the game. This method will simulate genetic inheritance of dominant/recessive alleles. Students should add a hash mark on their sheet of paper for each offspring they produce and for each additional offspring their offspring produces (i.e., descendants). If a student is able to collect at least three insects, they survive long enough to reproduce but then die and are out of the game. If they are unable to collect at least three insects, they die before they can reproduce and are out of the game/gene pool. On the board, write down the starting allele distribution of beak phenotypes (i.e., 75% chopstick, 25% spoon) and continue writing down this information following each round to record changes over time. Each round represents a generation. An example of what

the table might look like after a round of game play is illustrated in Figure 1C.

After approximately four to six rounds, pause the game and explain to students that their habitat has experienced a severe drought that has caused a significant reduction in the number of worms accessible to the birds in the soil. The beetles continue to thrive due to their protective exoskeleton, which protects them from desiccation. Alter the food source accordingly so that the frequency of worms and beetles is reversed (i.e., 60% round candy, 40% worms). This alteration represents an environmental shift in response to a natural disaster. Continue playing the game for another four to six rounds.

At the end of the game, the student(s) who produced the highest number of offspring and descendants wins. Following the completion of the game, have students return to their seats (with their acquired candy bounty) and prepare to discuss the outcomes of the game.

○ Interpreting the Results

The chopsticks are more efficient for collecting the gummy worms. Therefore, during the first few rounds of the game, allele frequencies should shift in favor of the chopstick-beaked phenotype. However, following the environmental disturbance that causes the round candy to become the more abundant food source, spoon-beaked individuals suddenly gain the advantage and we see allele frequencies shift in favor of that phenotype. *One important point to emphasize is that survival itself is not key to natural selection, but rather successful reproduction is.* The Natural Selection Game takes this into account by rewarding those who are most able to reproduce, while also demonstrating that an individual who does not survive can still reproduce and remain in the gene pool.

At this point, have students break up into groups and come up with answers to the following seven questions:

Question 1. What other examples of environmental disturbances could have caused the change we experienced in food source?

Answer 1. A migration event, an environmental pollutant, a shift in climate, a natural disaster, etc.

Question 2. Explain why some birds in this population had a phenotype that was not so favorable compared to others (i.e., how do "bad" traits exist in populations?).

Answer 2. Evolution is possible because populations possess genetic variation. Genetic variation is generated continuously by random mutations and sexual reproduction. Phenotypes considered favorable at one point can be considered detrimental at any other given point.

Question 3. Would this type of natural selection work if beak shape were not a genetically linked trait (i.e., if birds could not pass their beak shape down to offspring)?

Answer 3. No. In order for natural selection to drive evolution of a trait, the trait must be passed to offspring. Only genes, and therefore genetically linked traits, are heritable.

Question 4. Some individuals who were assigned the favorable beak phenotype were not as efficient at collecting food as other individuals with the same phenotype and died off. Can you think of a real-world parallel that could explain this situation in a population?

Answer 4. You would not expect all individuals with the favorable phenotype to be equally fit. There can be other factors affecting an individual's fitness level (e.g., high parasite loads, diseases, injuries).

Question 5. Naturally, we understand why an animal would need to acquire a certain amount of food to survive (i.e., avoid starvation). But can you explain how acquiring a certain amount of food could affect an animal's ability to reproduce?

Answer 5. The need to collect a certain amount of food not only affects mate choice where only individuals who are in good condition win mating opportunities, but also reflects the physiological and energetic costs of reproduction itself.

Question 6. How do you think the outcome of the game would differ if the two phenotypes were expressed from codominant alleles rather than dominant and recessive alleles?

Answer 6. If the most frequent genotype were heterozygous, then the population would consist mostly of intermediate-beaked birds (i.e., a cross between a chopstick and spoon).

Question 7. Let's say there was another island, 100 miles away, with the same species of bird but that island did not experience drought or a shift in food availability. After 10,000 years, lowered sea levels cause a land bridge to form between the two islands, and the two populations are now back in contact with each other but they can no longer breed with each other. What do you think would have caused that?

Answer 7. Given enough time, the continuous genetic drift between the two populations will be great enough that the two populations will no longer be able to produce viable offspring if they come into contact with each other. Perhaps they can mate but their offspring are sterile (i.e., postzygotic barrier), or they now have different behaviors or morphologies that prevent them from mating (i.e., prezygotic barrier).

Once students have had time to formulate their answers, select one random group per question to discuss their answer, leading each group to the correct answer if needed. Following this discussion, the instructor should relate the results of the game to real-world examples of natural selection (e.g., the shift in beak size of medium ground finches in response to a drought event, as described above). The students, having had a chance to explore and experience natural selection on their own first, are now ready to have the instructor assign the proper vocabulary and facts of evolution to their experiences.

○ Addressing Misconceptions about Evolution

At this stage, students should be equipped to address misconceptions about evolution. To address and engage student preconceptions of evolution, we present a critical-thinking activity that addresses common misconceptions of evolutionary theory after students have had a chance to explore and experience natural selection through the simulation game. In this activity, students are broken into groups of three

Table 2. List of common sources of information that students might encounter in their research, with a description of the quality and ranking of the reliability of the contents.

Source	Description of Contents	Reliability of Information
Peer-reviewed scientific papers (e.g., *Science*, *Nature*, *Journal of Mammalogy*, *Evolution*, *Journal of Zoology*, *Proceedings of the National Academy of Sciences*)	These are considered primary sources. They represent firsthand, unfiltered, and un-interpreted information. However, it is often hard to access them without access to institutional library accounts because many are locked behind a paywall. These are OK to cite and use as references when writing a scientific paper.	Very high
Books – nonfiction, single or multiple authors, with editor(s) and references (e.g., textbooks)	These are considered secondary sources. They consist of dry interpretations of information that has been gathered from primary sources. These are OK to cite and use as references when writing a scientific paper.	High
Books – nonfiction, single author, no references (e.g., popular books)	These are perspectives and opinions of individuals. They generally do not contain data or references. They are not OK to cite when writing a scientific paper.	Highly variable
Evidence-based science reporting (e.g., *Science Daily*, *Science Magazine*, *New Scientist*)	These resources provide well-presented evidence-based science. They are useful for learning about the latest science news without having to navigate through primary sources (i.e., peer-reviewed scientific journals). They are not OK to cite when writing a scientific paper.	High
Sensationalized science reporting (e.g., IFLScience.com)	These resources tend to sensationalize science news and do not provide thorough, evidence-based reporting. They are not OK to cite when writing a scientific paper.	Low
General news (e.g., CBS, FOX, *The Atlantic*, *Time*, *Forbes*, BBC, NPR, *The Huffington Post*, *Vox*)	These contain often sensationalized and badly interpreted science. However, many also contain well-interpreted and well-presented evidence-based science. They are not OK to cite when writing a scientific paper.	Highly variable

to five, and each group is presented with at least one common misconception about evolution. If time permits, groups can address all misconceptions. Fifteen examples of common misconceptions that can be used for this activity are listed in Table 2. The students are instructed to use any resources that they deem scientifically acceptable to explore and address their assigned misconception. We suggest using Table 3 as a guide to teaching students to identify acceptable and poor sources of information. The instructor should supply the students with clear and concise prompts that include the following:

1. Using evidence, describe what evidence contradicts this misconception.
2. Describe the scientific conception behind this misconception.
3. Using evidence, provide at least one example where the scientific conception behind the misconception has been scientifically supported and observed.

Following a period of group discussion, one representative from each group is asked to present their group's findings and key discussion points to the class in an informal manner. The instructor should also write or project the accurate scientific conception to ensure that the concept is solidified for students.

This activity allows students to address specific misconceptions and also encourages them to learn what resources are scientifically acceptable and what resources are poor through trial and error. In the current age of misinformation, differentiating between reliable and unreliable sources is a critical skill (Fitzgerald, 1997). Even providing a general guideline of the reliability of sources can be problematic. For example, the dramatic increase in predatory journals and the publication of articles perceived to be peer-reviewed (and thus reliable) can be confusing for students (Batholomew, 2014). This activity allows students to seek out websites and actively discuss the issues in small

Table 3. List of 15 misconceptions about evolution and accompanying reality. This list was adapted from the Understanding Science website (https://undsci.berkeley.edu/, University of California Museum of Paleontology, Berkeley).

Misconception	Scientific Conception
Because evolution is just a theory, it is not well supported.	Evolution is a well-supported, testable, repeatable, and predictable explanation of how species have changed over time.
Evolution is a theory about the origin of life.	Evolutionary biology deals with how life changed *after* its origin, regardless of how life originated.
Humans came from monkeys.	We share a common ancestor with other primates (i.e., monkeys and apes).
Evolution and natural selection are goal-oriented.	Natural selection is the result of variation, reproductive success (or failure), and heredity. It has no goal and is not striving toward a specific end product.
Evolution is random.	Mutations are random, as are the trait that they result in. Whether or not a trait is beneficial in its environment is not random. In other words, the variation of traits in a population is random, but selection acts on whichever traits are favorable at that time and place.
You cannot see evolution happening.	We can see examples of species with short generation times changing (evolving) over time (e.g., pesticide resistance in insects, antibiotic resistance in bacteria, shift in body size in fish).
Individual organisms can evolve within their life span.	Populations are the smallest unit of life that can evolve. Individuals cannot evolve. However, an individual can experience a mutation in its gametes (i.e., in its heritable genetic makeup) that contributes to the process.
Natural selection is the only mechanism by which organisms evolve.	Evolution can occur through natural selection, artificial selection, mutation, migration, and genetic drift.
Species will always evolve what they need to survive.	Species that cannot adapt fast enough to changes in the environment will die off. Species do not always get what they need.
Natural selection produces organisms perfectly suited for their environment.	Adaptations do not have to be perfect – just good enough to allow an organism to pass its genes to offspring.
"Survival of the fittest" means survival of the strongest.	"Survival of the fittest" refers to biological fitness – in other words, surviving long enough to reproduce.
Humans are no longer evolving.	Humans still face challenges to survival and reproduction and experience change over time (e.g., region-specific lactose intolerance and malaria resistance).
Natural selection involves organisms trying to adapt.	Natural selection leads to adaptation over time but does not involve effort. Either an individual has genes that are good enough to survive and reproduce or it does not; it cannot obtain the right genes by "trying."
Evolution is a theory in crisis and is collapsing as scientists lose confidence in it.	Evolutionary theory is not in crisis. Scientists do not debate whether evolution took place, but they do debate many details of how evolution occurred/occurs.
Evolution always leads to more complex organisms.	Evolution leads to change in species over time, but it may or may not increase the complexity of anatomy or physiology.

groups and with the instructor. This approach opens a dialogue to address misinformation issues and pushes students to defend their chosen site as "reliable." Besides allowing students to discuss the reliability of the sources they choose, this activity gives them power to engage in learning about their own potential misunderstandings while providing them time to share their findings with others.

○ Concluding Remarks

Teaching complex biological processes can be a challenge, especially in large lecture settings. Certain topics, such as evolution, can add additional challenge due to the political and religious underpinnings surrounding the theory. However, it is imperative that students are able to address common misconceptions and

understand the complex mechanisms so that they can become scientifically literate. We present these paired activities in hopes that other instructors can utilize them in their own classrooms to help combat scientific illiteracy.

○ Acknowledgments

References

Achieve Inc. (2013). *Next Generation Science Standards: Adoption and Implementation Workbook.* https://www.achieve.org/files/NGSS_Workbook_PDF-3.1.13.pdf.

Alters, B.J. & Alters, S. (2001). *Defending Evolution in the Classroom: A Guide to the Creation/Evolution Controversy*. Boston, MA: Jones & Bartlett.

Alters, B.J. & Nelson, C.E. (2002). Perspective: teaching evolution in higher education. *Evolution*, 56, 1891–1901.

Antolin, M.F. & Herbers, J.M. (2001). Perspective: evolution's struggle for existence in America's public schools. *Evolution*, 55, 2379–2388.

Batholomew, R.E. (2014). Science for sale: the rise of predatory journals. *Journal of the Royal Society of Medicine*, 107, 384–385.

Bishop, B.A. & Anderson, C.W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, 27, 415–427.

Brodie, E.D., Feldman, C.R., Hanifin, C.T., Motychak, J.E., Mulcahy, D.G. & Williams, B.L. (2005). Parallel arms races between garter snakes and newts involving tetrodotoxin as the phenotypic interface of coevolution. *Journal of Chemical Ecology*, 31, 343–356.

Cook, L.M. & Saccheri, I.J. (2013). The peppered moth and industrial melanism: evolution of a natural selection case study. *Heredity*, 110, 207–212.

Crawford, B.A., Zembal-Saul, C., Munford, D. & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching*, 42, 613–637.

Demastes, S.S., Settlage, J. & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: cases of replication and comparison. *Journal of Research in Science Teaching*, 32, 535–550.

Fitzgerald, M.A. (1997). Misinformation on the Internet: applying evaluation skills to online information. *Emergency Librarian*, 24, 9–14.

Friedrichsen, P.J., Linke, N. & Barnett, E. (2016). Biology teachers' professional development needs for teaching evolution. *Science Educator*, 25, 51–61.

Funk, C. & Rainie, L. (2015). Evolution and perceptions of scientific consensus. In *Americans, Politics and Science Issues* (pp. 88–104). Washington, DC: Pew Research Center.

Grant, P.R. & Grant, B.R. (2002). Adaptive radiation of Darwin's finches: recent data help explain how this famous group of Galapagos birds evolved, although gaps in our understanding remain. *American Scientist*, 90, 130–139.

Grisé, D.J., Lee, C.T., Bailey, C.M. & Rivera, M. (2011). Understanding and implementing team-based learning in large-lecture courses: summary of a workshop from the 2011 ESA Annual Meeting. *Bulletin of the Ecological Society of America*, 92, 406–411.

Grooms, J., Enderle, P. & Sampson, V. (2015). Coordinating scientific argumentation and the Next Generation Science Standards through argument driven inquiry. *Science Educator*, 24, 45–50.

Hoekstra, H.E., Drumm, K.E. & Nachman, W.M. (2004). Ecological genetics of adaptive color polymorphism in pocket mice: geographic variation in selected and neutral genes. *Evolution*, 58, 1329–1341.

Hoekstra, H.E., Hirschmann, R.J., Bundey, R.A., Insel, P.A., & Crossland, J.P. (2006). A single amino acid mutation contributes to adaptive beach mouse color pattern. *Science*, 313, 101–104.

Jones, M.R., Mills, L.S., Alves, P.C., Callahan, C.M., Alves, J.M., Lafferty, D.J., et al. (2018). Adaptive introgression underlies polymorphic seasonal camouflage in snowshoe hares. *Science*, 360, 1355–1358.

Kane, E.A., Broder, E.D., Warnock, A.C., Butler, C.M., Judish, A.L., Angeloni, L.M. & Ghalambor, C.K. (2018). Small fish, big questions: inquiry kits for teaching evolution. *American Biology Teacher*, 80, 124–131.

Lamichhaney, S., Han, F., Berglund, J., Wang, C., Almén, M.S., Webster, M.T., et al. (2016). A beak size locus in Darwin's finches facilitated character displacement during a drought. *Science*, 352, 470–474.

Lauren, H., Lutz, C., Wallon, R.C. & Hug, B. (2016). Integrating the dimensions of NGSS within a collaborative board game about honey bees. *American Biology Teacher*, 78, 755–763.

Lawson, A.E. & Weser, J. (1990). The rejection of nonscientific beliefs about life: effects of instruction and reasoning skills. *Journal of Research in Science Teaching*, 27, 589–606

Mills, L.S., Bragina, E.V., Kumar, A.V., Zimova, M., Lafferty, D.J., Feltner, J., et al. (2018). Winter color polymorphisms identify global hot spots for evolutionary rescue from climate change. *Science*, 359, 1033–1036.

Mullen, L.M. & Hoekstra, H.E. (2008). Natural selection along an environmental gradient: a classic cline in mouse pigmentation. *Evolution*, 62, 1555–1570.

Mullen, L.M., Vignieri, S.N., Gore, J.A. & Hoekstra, H.E. (2009). Adaptive basis of geographic variation: genetic, phenotypic and environmental differences among beach mouse populations. *Proceedings of the Royal Society of London B*, 276, 3809–3818.

Nelson, C.E. (2008). Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. *American Zoologist*, 48, 213–225.

Odom, A.L., Barrow, L.H. & Romine, W.L. (2017). Teaching osmosis to biology students. *American Biology Teacher*, 79, 473–479.

Puttick, G. & Drayton, B. (2017). Biocomplexity: aligning an "NGSS-ready" curriculum with NGSS performance expectations. *American Biology Teacher*, 79, 344–349.

Roehl, A., Reddy, S.L. & Shannon, G.J. (2013). The flipped classroom: an opportunity to engage millennial students through active learning strategies. *Journal of Family & Consumer Sciences*, 105, 44–49.

Rowland, J.M., Rowland, I.J. & Goodman, W.G. (2017). Teaching principles of endocrinology using the tobacco hornworm. *American Biology Teacher*, 79, 584–589.

Rutledge, M.L. & Mitchell, M.A. (2002). High school biology teachers' knowledge structure, acceptance & teaching of evolution. *American Biology Teacher*, 64, 21–28.

Smith, M.U. (1994). Counterpoint: belief, understanding, and the teaching of evolution. *Journal of Research in Science Teaching*, 31, 591–597.

Snyder, L.G. & Snyder, M.J. (2008). Teaching critical thinking and problem solving skills. *Journal of Research in Business Education*, 50, 90–99.

Sundberg, M.D. & Dini, M.L. (1993). Science majors versus nonmajors: is there a difference? *Journal of College Science Teaching*, 23, 299–304.

Tidon, R. & Lewontin, R.C. (2004). Teaching evolutionary biology. *Genetics and Molecular Biology*, 27, 124–131.

Walker, S.E. (2003). Active learning strategies to promote critical thinking. *Journal of Athletic Training*, 38, 263–267.

Zacharia, Z.C. (2005). The impact of interactive computer simulations on the nature and quality of postgraduate science teachers' explanations in physics. *International Journal of Science Education*, 27, 1741–1767.

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