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Sexual Selection as a Tool to Improve Student Reasoning of Evolution

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RESEARCH ON LEARNING

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Abstract

There is an emphasis on survival-based selection in biology education that can allow students to neglect other important evolutionary components, such as sexual selection, reproduction, and inheritance. Student understanding of the role of reproduction in evolution is as important as student understanding of the role of survival. Limiting instruction to survival-based scenarios (e.g., effect of food on Galapagos finch beak shape) may not provide students with enough context to guide them to complete evolutionary reasoning. Different selection forces can work in concert or oppose one another, and sexual selection can lead to the selection of trait variants that are maladaptive for survival. In semistructured interviews with undergraduate biology students (n = 12), we explored how leading students through a sequence of examples affected student reasoning of evolution. When presented with an example where sexual selection and survivability favored the same variant of a trait, students emphasized survival in their reasoning. When presented with a scenario where sexual selection selected for trait variants that were maladaptive for survival, more students described how two different selection forces contributed to evolutionary outcomes and described reproductive potential as a part of fitness. Moreover, these students considered how the maladaptive traits were inherited in the population. Scenarios where sexual selection and survival-based selection were opposed improved student ability to reason about how factors other than survival impact evolutionary change. When instructors introduce students to scenarios where survival-based selection and sexual selection are opposed, they allow students to change their reasoning toward inclusion of reproduction in their evolutionary reasoning.

Key Words: *evolution; sexual selection; biology education research; student reasoning.*

○ Introduction

Biology students who effectively engage in reasoning about evolutionary mechanisms readily recognize (1) trait variation in a population, (2) differential inheritance of the variable traits based on how those traits affect fitness, and (3) the impact of certain traits on an organism's ability to survive *and* reproduce (Gregory, 2009; Harms & Reuss, 2019). Traits that affect survival are commonplace in introductory biology, and many introductions to evolution use scenarios with traits that impact organisms' abilities to perform behaviors like feeding and predator avoidance (Maan & Seehausen, 2011). When asked about fitness, university biology students emphasize survival in their reasoning (Kampourakis & Zogza, 2008; Beggrow & Nehm, 2012; Perez et al., 2013). However, a trait's effect on the ability of an organism to reproduce is an equally important factor to consider when assessing fitness and making evolutionary predictions (Scheuch et al., 2019). To make complete predictions about future generations, students must include reproduction and inheritance in their reasoning in addition to their reasoning about survival.

Informal introductions to evolutionary ideas may contribute to an overuse of survival-based evolutionary reasoning (Nehm et al., 2010). Terms like *adaptation* and *survival of the fittest* can be misinterpreted in biology classrooms, based on their use in everyday conversation (Bishop & Anderson, 1990). For example, *survival of the fittest* suggests that fitness is based on survival alone and probably influences students to overemphasize survival in their reasoning (Ferrari & Chi, 1998; Gregory, 2009). Some students explain that if an organism has a trait that benefits survival (e.g., improved antipredator response, strength, access to food), the organism will survive longer, providing more opportunities mate (Bishop & Anderson, 1990). While survival is an important component of fitness, students who rely on survival to evaluate fitness are missing the equal importance of reproduction in their reasoning. Few students describe how traits that directly improve an organism's ability to mate may also benefit fitness by providing more opportunities to reproduce and pass on their traits (Nehm & Reilly, 2007). Therefore, examples that emphasize the role of reproduction in fitness may provide opportunities for students to improve their ability to incorporate reproduction into their evolutionary reasoning.

In addition to emphasizing survival, students may reason that individuals (instead of populations) sometimes modify a trait to satisfy a need (e.g., avoid a predator, obtain resources) and pass the modified trait to offspring (Bishop & Anderson, 1990; Harms & Reiss, 2019). This reasoning does not address the genetic basis of traits, how variation in traits arises, and how traits are typically

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inherited. Students who equally include reproduction in their reasoning are considering inheritance when they predict evolutionary change. Students who do not also consider the role of reproduction in their reasoning may not consider the important role of inheritance in their predictions. They may incorrectly reason that an individual evolves certain traits to meet a need, rather than that the alleles for the trait are differentially inherited in the population. Therefore, improved student reasoning of the role of reproduction in evolution may help them recognize that traits are differentially inherited over many generations and do not change in a single lifetime (Kampourakis & Zogza, 2008; Harms & Reiss, 2019).

Sexual selection can serve as an alternate explanation for variation and differential fitness in populations. Sexual selection is selection based on the ability of an individual to mate. Examples that include sexual selection allow instructors to introduce variation and fitness in a way that is similar to the way they are introduced in examples that include survival-based selection. However, sexual selection examples may allow students to better relate reproduction and inheritance to evolutionary change. Sexual selection can select for the same type of trait as survival-based selection, causing strong selection for that trait variant. For example, bright red skin color in strawberry poison dart frogs (*Oophaga pumilio*) serves as a warning sign to ward off predators, but it is also attractive to females, so both survival-based selection and sexual selection select for the bright red skin trait (Maan & Seehausen, 2011). Alternatively, sexual selection can select for traits that do not benefit survival, but rather benefit an individual's ability to mate (Ritchie, 2007; Chenoweth et al., 2015). For example, in long-tailed widowbirds (*Euplectes progne*), males with short tails are better at escaping predators, but females prefer to mate with males with long tails. Conflicting selection pressures led to males having much longer tails than females in the population. This example describes a trait that does not benefit survival, because males with longer tails are preyed upon at higher rates (Andersson, 1982). It also provides an example of sexual dimorphism, when males and females of the same species have different phenotypes. Sexual dimorphism is a result of sexual selection acting on the two sexes differently. Introducing students to scenarios where sexual selection does not benefit survival may help students recognize that survival-based reasoning alone does not explain all mechanisms of evolutionary change (Scheuch et al., 2019).

A study that explored the gaps in biology education research revealed the need for more studies on sexual selection, with only four published at the time (Ziadie & Andrews, 2018). One study explored sexual selection in a lab experiment, but the examples in the study were limited to adaptive traits (e.g., aposematic skin coloring in frogs) (Eason & Sherman, 2003). In another study, undergraduate students engaged with maladaptive traits (like widowbird tail length) in lab experiences, and they included reproduction in their explanations of why the trait would evolve (Bouwma-Gearhart & Bouwma, 2015). Another study developed a learning progression across many topics related to evolution, including survival-based and sexual selection. As learning progressed, students accurately included mechanisms of evolutionary change in sexual selection examples (Scheuch et al., 2019). Our study differs from the Scheuch et al. 2019 paper in that we started with an example where selection of a trait could be for both survival and reproduction. Then we introduced dissonance, where the selection of a seemingly maladaptive trait improves reproduction. This design allowed us to qualitatively describe how students changed their reasoning of fitness and inheritance in scenarios that differ in how sexual selection is presented.

We used interviews to assess student ability to describe how traits impact fitness through mating success and also student proclivity to include inheritance as part of the process of evolution. Students were asked to describe the evolutionary implications of different scenarios; in some, survival-based selection and sexual selection reinforced one another, and in others, they opposed one another. Responses were qualitatively analyzed to determine how the context of different selection forces affected student ability to (1) describe how mating success influences fitness and (2) include inheritance in their descriptions of evolutionary change over time. We predicted that when students were presented with scenarios where survival-based selection and sexual selection selected for opposing traits, more students would include how the ability to acquire a mate affects fitness and evolutionary change over time. Additionally, we predicted that when students were presented with these scenarios, more students would directly include inheritance in their evolutionary reasoning. We propose that instruction that progresses from survival-based selection, to reinforcing selection, to opposing selection will support the inclusion of reproduction and inheritance in student reasoning of evolutionary mechanisms.

○ Methods

To explore student reasoning of the role of mate choice and sexual selection in evolution, we interviewed introductory biology students at a large Midwestern university following instruction of evolutionary concepts. Students were recruited from two large lecture sections (about 250 students total), and of the 20 students who responded, 12 students were interviewed. Semistructured interviews were conducted orally, with images pertaining to the questions provided on paper. Students were presented with four scenarios: (1) Darwin's finches, (2) poison dart frogs, (3) long-tailed widowbirds, and (4) noise pollution and black-capped chickadees. The students were then questioned about fitness and evolution. Prior to this study, students had only been introduced to Darwin's finches in class instruction. The order of the scenarios follows a progression of increasingly more apparent (to the researchers) presentations of sexual selection. Students were prompted to describe the evolutionary processes in these scenarios.

The focus of this paper follows two prompts that introduced students to factors that may affect the evolution of a population. The two prompts differed in how both sexual selection and survival-based selection acted on the population. The first scenario included the skin color trait of strawberry poison dart frogs. Frogs with skin that is brighter red deter more predators than those with paler red skin, and female frogs are attracted to males with brighter red skin (Maan & Cummings, 2009). Therefore, the bright red skin color trait benefits both survival and reproduction for the frogs. In a second scenario, with long-tailed widowbirds, males with shorter tails are less likely to be captured by predators, and males with long tails are more likely to attract females (Andersson, 1982). The widowbird scenario provides an example where a trait (i.e., long tail) may be beneficial for attracting mates but maladaptive for survival. The two scenarios were chosen based on their different presentations of survival-based selection and sexual selection, to determine whether there is an effect on student reasoning. Students were presented with the scenarios in the same order so that the widowbird scenario would not prime students to detect sexual selection where they usually would not (i.e., the frog example). While this does have the shortcoming of a possible order effect, due to small sample size, we chose this method to determine the effect of sexual selection examples on student reasoning of evolution.

For part 1 of each scenario, students were shown a picture of a male and female next to one another and asked the following questions:

1. Are there observable differences between the male and female frogs/widowbirds? Why?
2. Do you think a predator would avoid males or females more? Why?
3. How does skin color/tail length affect fitness?

For part 2 of each scenario, students were shown a drawing of a population of about 50 male frogs that varied by skin color, and about 50 male widowbirds that varied in tail length. Students were then asked two questions:

1. What do you observe about the male population?
2. Describe how evolution has acted on this population to cause it to appear as it does currently.

Students' responses indicated whether students recognized that males and females of the same species can have variation in traits and that male fitness may be impacted by mate choice. Student responses to part 1 were evaluated at three levels (Table 1): (level 1, low) the student used survival-based reasoning alone (no students used mating-based reasoning alone to describe fitness); (level 2, medium) the student applied mating to the assessment of the fitness of an organism; or (level 3, high) the student described how the ability to acquire a mate influenced evolutionary change over time. Student responses to part 2 of each question were also coded based on the description of the effects of inheritance on changes in a population over time (Table 1): (level 1, low) the student did not include any inheritance in their response, (level 2, medium) the student described a connection between reproductive potential and change over time, and it could be inferred that the student considered inheritance as the link between the two; (level 3, high) students directly described the passing on of genes, traits, or characteristics in the context of evolutionary change in a population.

We used the constant comparative method to qualitatively analyze student interview responses, first building a profile of the students' responses and then comparing student responses for each example (Boeije, 2002). The two authors reviewed a sample of responses from two students and compared them with a rubric developed by Salter and Momsen (2018). This produced a preliminary coding rubric. Then, another small sample of responses (four random fitness responses and four random evolution responses) were coded by the same two individuals. Codes were compared, discussed, and revised to address the minimal discrepancies. Then one author (SS) coded the remainder of student responses with the revised coding rubric. Statistical analyses were not applied to the results, as sample size limited the strength of conclusions that might be drawn from statistics.

○ Results

Fitness

In the frog scenario, all 12 students described sexual dimorphism when presented with images of a male and female frog. Mate choice (female mating preference) influences the difference in skin color between male and female frogs. However, most students included only survival in their descriptions of how skin color affected fitness in male frogs. When students were asked how skin color affected fitness, all students described how brighter color increased the survival of male frogs by deterring predators: "If you have a brighter color, you have a better chance of surviving because they're not going to eat you." Most students connected fitness to survival, although

Table 1. The coding rubric used to evaluate descriptions of fitness and inheritance in student responses to questions about fitness and evolutionary change over time. Themes and example student descriptions were ranked at level 1, level 2, or level 3 for application of mate choice and inheritance.

	Fitness	Inheritance
Level 1 (Low)	**The student used survival-based reasoning only.** *It affects fitness because it helps them survive. It's camouflage or, in the male's case, an alert. It helps them ward off predators.*	**The student did not include inheritance in their response.** *It brought along more dark red males because it was successful in surviving against predators, and the paler red weren't as successful surviving so they died off and the red frogs kept going.*
Level 2 (Medium)	**The student described how the ability to acquire a mate can impact fitness.** *It makes you easier to spot, which makes you more likely to be caught by a predator, but it also helps you find a mate and pass on your traits, which would make you a more fit organism.*	**The student included a connection between reproduction and change over time; inheritance can be inferred.** *More red ones are able to reproduce, and so that causes the population to be kind of shifted towards the red side.*
Level 3 (High)	**The student applied accurate descriptions of fitness to evolutionary change over time.** *The ones with the intermediate tail are better at escaping predators and getting mates so they reproduce more. Then that gene for the intermediate tail would increase [in the population] because those birds have higher fitness.*	**The student directly included inheritance or the passing on of traits.** *They were able to mate and reproduce and pass on their trait of having an intermediate sized tail to their offspring.*

2 students included female mate preference in their descriptions of the fitness of males (Figure 1):

The female frogs know that a brighter color implies a bigger fitness from the male. In that case it will try to mate with the male that has a brighter color, and that way he will be able to produce more offspring than if he didn't have such a bright color.

Overall, students were more likely to include only survival in their descriptions of fitness, even when students recognized a difference in male and female skin color.

Survival-based selection was invoked more often than sexual selection when students described how evolutionary change acted on the frog population. When students were asked how evolution led to a population with more bright red individuals, they explained that increased survival of bright red individuals led to increased prominence of bright red individuals in the population. For example, a student stated:

These organisms with the brighter colors would probably be more successful in finding mates and passing on their genetic traits because if they have a more vibrant color, then predators will avoid them more than say a frog with a lighter red.... The darker red frogs, since they survived to adulthood and were more successful in finding a mate, they were more likely to have their offspring survive, and if their offspring survive, that means their traits survive.

The same 2 students who applied mate choice to fitness were the only two who described how both mate choice and survival influenced the evolution of frogs: "The bright ones have more offspring because they are more successful.... They must be attracting mates. They could help them live longer, but if they're reproducing, then it must be attracting mates." The other 10 students did not include how mate choice contributed to evolutionary change, and they left out sexual selection as a possible selection pressure. When survival-based selection and sexual selection were reinforcing one another and selecting for the same trait (frog skin color), survival dominated students' reasoning of fitness and evolutionary change over time.

The widowbird scenario highlighted opposing selection pressures, with sexual selection and survival-based selection selecting for longer and shorter tail lengths, respectively. As with the frog scenario, all students identified sexual dimorphism. Differences emerged when students were asked about fitness, as 10 students explained how mate choice may influence individual fitness (Figure 1). Eight students that had not included mate choice in their descriptions of fitness in the frog scenario *did* include how mate choice may impact widowbird fitness. Students explained that having a long tail attracted mates but also made it harder to escape predators, applying both survival and mate choice to fitness. For example, when describing how tail length influenced male fitness, a student explained:

It probably helps them get more mates because it's attractive for female birds, but it probably also decreases their chances for survival, at least compared to females, because of them taking up more space and making it easier for predators to catch them.

In contrast to the frog scenario, in the widowbird scenario students described sexual dimorphism *and* described how mate choice influenced fitness.

In their descriptions of widowbird evolutionary change over time, 8 students included how both survival-based selection and sexual selection acted on the population (Figure 1). The students described how female mate choice selected for long tails and survival selected for short tails that led to a higher frequency of males with a medium tail length in the population. For example, one student explained:

The medium-sized tail would be able to get away from a predator easier than the ones with the long tail, but then they would be able to find a mate better than the ones with the short tail, so the medium length tail mutation and gene was passed down more frequently.

Of the 10 students who did not include how sexual selection influenced evolution in the frog scenario, 6 students applied sexual selection to evolutionary change in the widowbird scenario. Students were able to extend the reasoning about mate choice to include the effect mate choice may have on changes in a population over many generations.

Inheritance

Where selection pressures were opposing (widowbirds), students were more likely to reference inheritance of genetic information than where selection favored the same trait (frogs). In the frog scenario, six students included inheritance directly, using "inherited" or "passed on" when describing evolutionary change, and five students included responses where inheritance could be inferred (Figure 2). These five students described how a trait increased reproductive potential or number of offspring and led to an increase of that trait in the population, but they did not directly include inheritance:

I see more red than orange. I guess that the red frogs were more successful in having offspring, so that caused the population to have a change in the alleles so that more of the frogs nowadays are red than they were in the past.

We inferred that the student was describing inheritance, but incompletely. Many students used terms like *gradual*, *eventually*, and *slowly* to describe a change in evolutionary time and had a lack of clarity with regard to changes occurring in the population over generations:

So then slowly as the lighter ones got preyed upon, there would be less of those, so the brighter ones would reproduce more. It would, not overtake, but there would be more compared to the lighter ones.

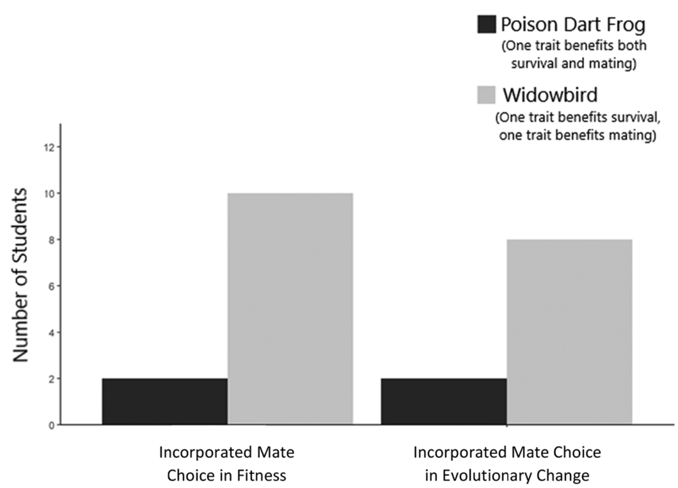

Figure 1. Inclusion of mate choice in reasoning about evolutionary change. Students included mate choice more frequently where survival-based selection and sexual selection were opposed (widowbird tail length) than where they selected for the same trait variant (frog skin color).

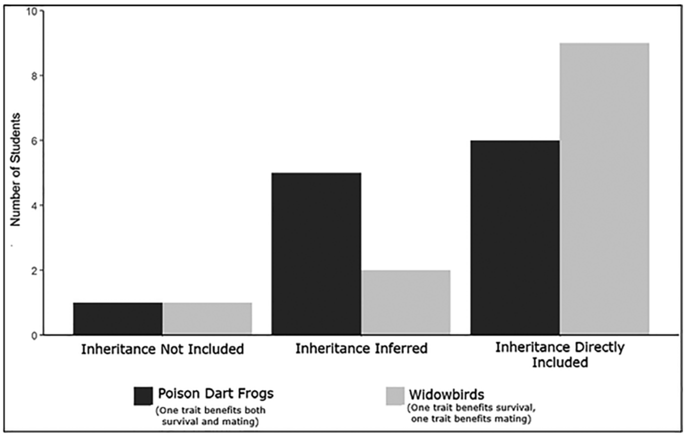

Figure 2. Inclusion of inheritance in reasoning about evolutionary change. Students included inheritance more frequently where survival-based selection and sexual selection were opposed (widowbirds) than where they selected for the same trait variant (frogs). While inheritance was included in most student responses, the widowbird scenario elicited direct statements about inheritance.

Approximately half of the students directly referenced inheritance of skin color when describing population adaptations, and the remainder seemed to imply inheritance was necessary.

In the widowbird scenario, nine students had responses that included inheritance directly, and two students included responses where inheritance could be inferred but was not directly stated (Figure 2). When two selection forces were opposing, inheritance of the intermediate trait entered into the description:

There might be less of the short tails because they couldn't find a mate to reproduce so they couldn't pass on that short tail. Then the long tail, there might be less of them because they were being hunted more often so then they die and can't reproduce…. [The males with intermediate tails] were able to mate and reproduce and pass on their trait of having an intermediate-sized tail to their offspring.

This student described the passing on of traits (inheritance) when two selection forces were selecting for opposing variants of traits. As observed with this student, more students directly included inheritance in their descriptions of evolutionary change over time in their responses to the widowbird scenario than to the frog scenario.

○ Discussion

A common goal of biology instructors is for students to improve their ability to apply important evolutionary components like fitness and inheritance to novel evolutionary scenarios (Gregory, 2009; Harms & Reuss, 2019). Many students emphasize survival in their evolutionary reasoning (Gregory, 2009; Beggrow & Nehm, 2012), which may cause them to leave out other evolutionary components that must be included for accurate evolutionary reasoning. In our study, we observed an emphasis on survival in the frog scenario, where both survival-based selection and sexual selection favored bright red skin color (Figure 1). All students recognized sexual dimorphism in the frogs, but most students did not describe how female mate choice led to males having a brighter skin color. When describing fitness, most students only used survival-based reasoning, leaving out the role of mate choice. The frog scenario also led few students to show a complete application of inheritance to their reasoning of evolutionary change in the population (Figure 2). In our study, showing an example where survival-based selection and sexual selection acted in concert (i.e., frog scenario) was insufficient to generate complete descriptions of fitness and inheritance from most students.

When students were presented with a scenario where survival-based selection and sexual selection selected for opposing traits, students progressed, from simply addressing sexual dimorphism, to describing the mechanisms behind it. In the widowbird scenario, more students included mate choice in their evaluation of male fitness (Figure 1). The progression from reinforcing selection pressures to opposing selection pressures seemed to guide students to consider the role of differential reproduction as well as the role of differential survival. Our results provide evidence that when sexual selection and survival-based selection are opposed, it provides students the opportunity to observe multiple mechanisms of fitness and evolutionary change (Scheuch et al., 2019). One benefit of starting with survival-based selection and reinforcing selection examples is that it meets students where they already are, since many students already have decent knowledge of survival aspects of fitness (Beggrow & Nehm, 2012) and they can build upon that knowledge.

Using scenarios where selection pressures are opposed may also serve to improve student ability to apply inheritance to evolutionary change over time. Most students applied a more complete description of inheritance to their descriptions of evolutionary change in the widowbird population (Figure 2). The close connection between reproduction and inheritance may explain why student responses included inheritance more directly when the survival-based selection and sexual selection selected for opposing trait variants. Inheritance plays an integral role in evolution, as inheritance patterns over generations contribute to changes in the population over time (Gregory, 2009). Many students possess the misconception that traits evolve based on need or use within a lifetime (Bishop & Anderson, 1990; Gregory, 2009; Harms & Reiss, 2019). If students have a better understanding of the role of inheritance in evolution, they are more likely to recognize how a trait that impacts an individual's ability to mate may influence inheritance patterns in the population. Students showed this improvement in the interviews.

The ability for students to better apply mate choice and inheritance when selection pressures are opposed has been observed in other studies, providing further evidence that introducing students to scenarios where survival-based selection and sexual selection select for opposing trait variations promotes important learning gains with regard to understanding the important non-survival-based mechanisms behind evolutionary change over time (Eason & Sherman, 2003; Andrews et al., 2012; Bouwma-Gearhart & Bouwma, 2015; Scheuch et al., 2019). The observations from these studies align with our observations that a student's evaluation of fitness can change from an emphasis on survival ("If a predator was more threatened by the brighter red, that frog would survive. That would probably mean they have higher fitness") to an evaluation that includes survival and reproduction ("The longer length might make it easier for predators … there might be less of the shorter length because it might be trying to attract females"). When making predictions about inheritance and evolutionary change, students can progress from "More red ones are able to reproduce, so that causes the population to be shifted towards the red side" to "Alleles for medium length tail have been the ones who can both get some mates and have a better chance of survival…. And so those are the ones that survive and reproduce, keep passing on their genetic information." Instructors can introduce survival-based selection concepts with typical examples (e.g., Darwin's finches) and then layer on sexual selection through an example where sexual selection is concurrent with survival-based selection, followed by an example where the selection pressures are opposed. One limitation of our study was that the order of the examples did not vary, because we wanted to observe changes in student descriptions. Further studies with larger sample sizes can control for the ordering of the examples, run statistical analyses, and consider application of this reasoning in novel scenarios.

Consideration of multiple selection forces is necessary for making complete predictions about evolutionary change. Activities that guide students to observe the interactions between multiple selection forces provide students with the opportunity to practice more complete reasoning. Instructors who utilize this effective way to introduce students to the roles of reproduction, mate choice, and inheritance in evolution will push students to integrate and apply important evolutionary components. We can use the opposing sexual selection force as a tool to improve student reasoning about how sexual selection may influence differential reproduction and inheritance in a population and to introduce novice biology students to the complexity of selection pressure interactions. As instructors move beyond survival-based selection scenarios, students will be better prepared to more completely reason through increasingly complicated evolutionary scenarios.

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