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The predator-prey game: Revisiting industrial melanism and optimal foraging theory outdoors with biology undergraduates

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ABSTRACT

Teaching natural selection and adaptations in undergraduate biology classrooms is often undertaken with the example of the *Biston* peppered moth, a well-documented case of industrial melanism. However, the idea of optimal foraging theory, a behavioral ecological model that includes predators searching for prey, may be overlooked when teaching this classic example of natural selection and predator/prey dynamics. To this end, we developed a simulated predator/prey activity to teach both of these concepts using different size and color toy lizards, moths, and snakes as part of an outdoor laboratory. Students overwhelmingly viewed the laboratory as an engaging way to learn about natural selection (100%, n=115), and how predators forage (Likert median score=5, n=115). We recommend biology instructors across science academic levels (high school and college) incorporate or modify this activity for student-based data collection, as it concomitantly engages undergraduates while providing a hands-on approach to biological and evolutionary theory of natural selection.

Keywords: biology pedagogy, evolution education, environmental instruction, outdoor laboratories, teaching science

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INTRODUCTION

There remain many challenges to teaching science to undergraduates, including the dissemination of clear, engaging pedagogies and learning activities, which both engage and inform in the instruction of evolution and natural selection (Johnson & Lark, 2018). Among the challenges involve instructor knowledge base on the nature of science and employing activities that utilize active instruction approaches that minimize misconceptions about science (Bugingo et al., 2022). Moreover, active learning methods are more commonly being studied to increase student learning over more traditional lecture approaches in undergraduate STEM courses, which include group work and the use of worksheets (Weir et al., 2019). Therefore, finding effective methods of teaching the concepts of predator/prey dynamics is a vital component to the fundamental understanding of its effect on classic examples of natural selection, including how predators find prey as it relates to industrial melanism as evidence for evolution and in particular when viewed through the perspective of optimal foraging theory.

There have been previous efforts that have focused on predator/prey dynamics approaches to biological instruction across academic levels. Teaching optimal foraging can include designing experiments using various food items and bird feeders (Pecor et al., 2015). Moreover, plasticine color models have been placed outdoors, which mimic caterpillars to learn about predation (Leuenberger et al., 2019), as well as clay caterpillars to allow students to investigate patterns of predation in edge versus forest habitats (Barber, 2012). Models of predators and even eggs, have allowed behavioral researchers to identify predators of smaller prey animals based on teeth, claw, or beak marks left on models (Bateman et al., 2017). The backbone of many of these methods include teaching that more cryptically camouflaged individuals may “blend in” more with their surrounding environment or specific habitat when compared to non-camouflaged individuals. Therefore, while there are many methods that emphasize unique teaching tools that involve hands-on approaches and the collection of data, further work is needed to develop laboratories that balance effective instruction with practical limitations of both time and costs of teaching science to maximize student interest in the subject matter of natural selection.

Student understanding of evolution and natural selection is fundamental in college biology courses (Ziadie & Andrews, 2018), however, can be challenging and require students to overcome common misconceptions about evolutionary theory and processes (Gregory, 2009). Moreover, while natural selection is the “glue that binds” evolutionary theory and biology, many students have gaps in their understanding of natural selection (Anderson et al., 2002), even following standard instruction (Abraham et al., 2009). The peppered

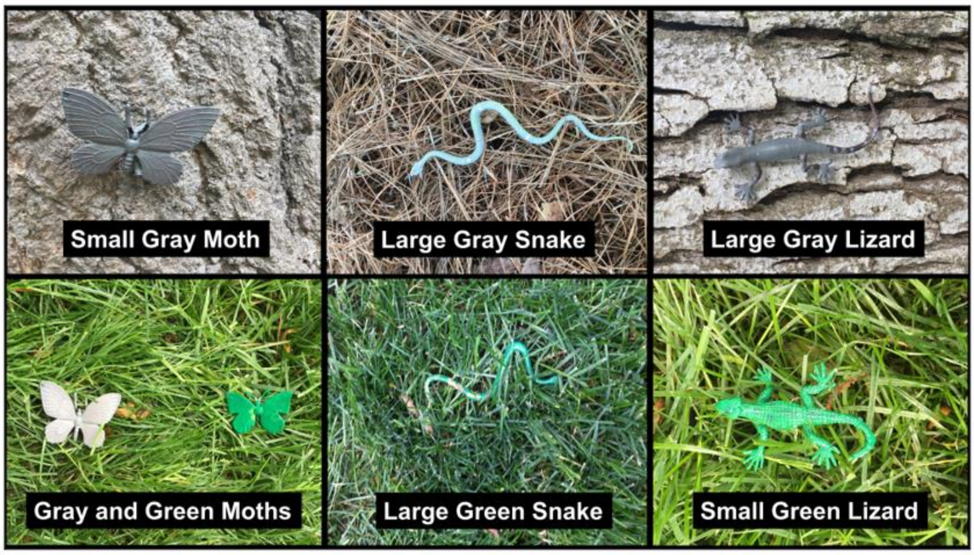

Figure 1. Images of "prey" items used in activity showing diversity of color, size, & animal type on various backgrounds (grass, tree, & pine straw) (Source: Shem Unger)

moth is a well-documented and common teaching example of both natural selection and industrial melanism (Majerus, 2009), which has increasingly been used in textbooks to convey natural selection to college-level biology students (Fulford & Rudge, 2016). Teaching industrial melanism can occur outside of lecture or textbook examples by including computer simulations (Church & Hand, 1992), or other methods. As industrial melanism implies changes in predator/prey dynamics, it opens the door to further teach optimal foraging of predators on prey. Teaching optimal foraging "animals foraging behavior maximizes net energy gain per unit time", or alternatively "how animals behave when searching for food" can occur by having students make field observations on the frequency of butterflies visiting flowers and having students design experiments (Schwagmeyer & Strickler, 2011).

Alternative methods can incorporate models such as using physical nuts and bolts, whereby students simulate finding and handling prey (Thomson, 1980) similar to teaching adaptation using physical phenotypes using office supplies (Janulaw & Scotchmoor, 2011). Teaching natural selection by incorporating a gaming approach has also been found to develop stronger connections between lecture and laboratory and promote active learning (Mohammadi et al., 2020). While both computer and physical simulations can effectively teach natural selection and related concepts in larger classroom/lab settings (Pope et al., 2017), incorporating a field component to outdoor simulations has the potential to further engage while concomitantly teaching natural selection and allowing students to generate and examine their own hands-on data.

Incorporating field components into biology laboratories has been shown to enhance environmental literacy and creativity (Fleischner et al., 2017), with the benefits of using the outdoors as both a laboratory and classroom to further understand the process of science and ability for students to think critically and develop observational skills (Chrouser, 1975). Also, this field-based education can impart a variety of skills while also engaging undergraduates and providing avenues for hands-on discovery in science (Eisner, 1982). These outdoor experiences may take form of incorporating smartphone applications to identify species (Thomas & Fellowes, 2017), or sampling organisms from field gaining knowledge on local biodiversity (Scott et al., 2012).

In this study, we assessed whether a newly developed outdoor laboratory would successfully engage students while teaching them about optimal foraging theory and industrial melanism. Student comprehension of prey camouflage and the ability of predators to detect prey are both key strategies related to these fundamental evolutionary and ecological concepts. In this activity, we address two primary questions:

1. Are students more engaged by performing this outdoor laboratory acting as "foraging predators" in groups versus individually?
2. Did students actively learn and find the activity engaging while learning about optimal foraging theory and industrial melanism?

Given the importance of these classical examples of natural selection and evolution, disseminating knowledge in a manner that allows students to both learn and actively participate was among our main aims of this activity. Therefore, we present the primary findings of this activity as an effective method to teach natural selection from the perspective of predator/prey relationships as it pertains to industrial melanism, a classical example of evolution in action.

METHODOLOGY

Research Design

This activity was developed as part of an undergraduate organismal biology laboratory on evolution and natural selection. Prior to conducting the activity, students attended a brief lecture and were provided with a worksheet on natural selection and evolutionary theory, with the primary example as the *Biston betularia*, peppered moth experiment/observation of industrial melanism. Following this pre-laboratory overview, students then participated in an outdoor lab activity. For laboratory setup, large and small-sized plastic animals (snakes, lizards, and moths) were spray-painted either gray or green on both sides. These were allowed to dry for at least two days prior to the

Figure 2. Map showing approximate placement of prey items according to zones (1, 2, & 3) (randomization of prey items [L: Lizard, M: Moth, S: Snake; & G: Gray & green] within zone [inset]) (Source: Google Maps; Shem Unger)

	Small Snake	Large Snake	Small Moth	Large Moth	Small Lizard	Large Lizard	*Totals*
Green							
Grey							
Totals							

Table 1. Prey items obtained by the ***individual***.

	Small Snake	Large Snake	Small Moth	Large Moth	Small Lizard	Large Lizard	*Totals*
Green							
Grey							
Totals							

Table 2. Prey items obtained by the ***group***.

Figure 3. Example worksheet table filled out by student participants for individual & group data obtained during this outdoor activity (Source: Shem Unger)

activity. All prey types were carefully placed across each zone on campus as part of a first-year organismal biology laboratory, during Fall of 2022 and Spring of 2023 (**Figure 1**).

Moths were duct taped to trees, in addition to lizards, and also placed in either grass or pine straw, whereas snakes were only placed at the base of trees, in grass, or in pine straw. Either four or five of each color and size "prey" were placed out just prior to this outdoor laboratory activity, to randomize slightly the number of prey items found in the sample area or "nature". Following each trial, zones were reset with "prey" repositioned within each zone, but not always in the exact location to further mimic nature and ensure students searched the entire habitat within each zone for each trial. The repositioning of "prey" can be done by the instructor, or by the students before they progress to the next zone.

Activity Data Collection

Students were grouped near one zone, instructed to only search within a specific area or zone for any potential "prey" items (**Figure 2**).

Each zone included three trees with pine straw around trees with the majority of the zone occupied by grass. Zone one included an area of ~660.1 m^2, zone two an area of ~585.8 m^2, and zone three an area of ~401.5 m^2. Groups consisted of four students per zone. Students in groups were then given one minute to "capture" as many "prey" in their search zone. Immediately following the one-minute search window, individual students filled out the first table for individual captures, noting how many of each animal type, color, and size of prey they captured (**Figure 3**).

Zones were reset, and students worked their way through all three zones and reported their results. Next groups completed the second table to determine how many as a group of predators they were able to obtain in their search zone. Lastly, they compared the results of their group of predators with other groups foraging in different zones. Students then answered questions in their lab worksheet on which type, color, and size of prey item was captured the most, either individually or across groups based on their data. Additional questions in the worksheet included whether there was variation between groups and what trends would students expect to occur in a population over time based on size and color morphology of prey items. Reflection questions immediately following the activity were posed to students including "*If you needed at least five total items per individual, did every predator in the group survive?*". This was followed by a brief discussion on differences

Table 1. Examples of student responses to activity for A, B, C, & D questions (n=115)

Survey	Student responses
A. "*Was this lab an engaging way to learn about natural selection & how predators forage for prey?*"	100% Yes & 0.0% No
B. "*On a scale of 1 to 6, how much did predator foraging game help you to learn about how predators forage & natural selection?*"	Median=5
C. "*On a scale of 1 to 6, was predator foraging game helpful in learning about how traits/adaptations of prey allow them to survive predation?*"	Median=5
D. "*Additional comments on predator foraging game activity*"	*"I thought it was interesting to be in the mind of a predator." "I learn better hands on, it was great to see how people see differently when foraging." "I loved this activity, I thought it was fun and insightful. The best thing about this activity is how hard it can be for predators to find their prey." "I think the fact you had to really become observant, & search allowed for one to see how "predators" have to search for food across habitats." "I noticed that I was able to find many more gray organisms than green. I found this interesting because of camouflage and natural selection." "The most interesting concept I learned was how hard it was to find animals that blended in with their background environment. I see how evolution benefits prey and predator." "This outdoor lab was both fun and practical in learning about natural selection." "It was great to see how people see differently when hunting for prey or "foraging" as a predator & how much variation there is among students & groups. I learn better hands on, & this was a great activity."*

between the individual student foraging and a group, and also across different groups foraging in different zones or other student groups.

Post-Activity Survey

Student participants completed a short follow-up survey immediately following the activity (**Appendix A**).

The questions were geared towards having students assess their knowledge based on the activity of the predator/prey dynamic, natural selection, and level of engagement of this activity. This survey consisted of four questions:

A. "*Was this lab an engaging way to learn about natural selection and how predators forage for prey?*",

B. "*On a scale of one to six, how much did the predator foraging game help you learn about how predators forage and natural selection?*",

C. "*On a scale of one to six, was the predator foraging game helpful in learning about how traits/adaptions of prey allow them to survive predation?*", and

D. "*Additional comments on the predator foraging game activity*".

Questions B and C used a Likert question scale of one to six (1=strongly disagree, 2=disagree, 3=slightly disagree, 4=slightly agree, 5=agree, and 6=strongly agree).

Analyzing of Data

Data were analyzed primarily focusing on the survey for the assessment of this activity (descriptive statistics), and we report on general trends for student data collected during this activity. We ran a chi-square analysis on responses to survey questions B and C using data obtained from these survey questions as interval data.

FINDINGS/RESULTS

Comments from students indicate students overwhelmingly found this activity to be an engaging way to learn about natural selection, industrial melanism, and optimal foraging theory, with 100% of participant responses answering yes to question A (**Table 1**).

For question B ("*learning about predator foraging and natural selection*"), and C ("*how traits and adaptations of prey help them survive predation*"), participants responded, with a mean of 5.140±0.804 standard deviation (SD) and median of five (min=2, max=6), mean of 5.300±0.691 SD and median of five (min=3, max=6), respectively. We found significance when analyzing responses to question B; X^2 (1, n=115)=55.608, $p<0.0001$ and also when analyzing responses to question C; X^2 (1, n=115)=46.324, $p<0.0001$. Based on student-reported data and answers in lab worksheets, individual students on average found more small green moths and small lizards whereas for gray, they found more small and large snakes. Qualitatively, students found a higher relative number of gray prey items versus green, likely due to gray contrasting in many cases against the green grass. Overall, feedback from post-laboratory activity and discussion following the laboratory was positive with student participants pointing out they learn better hands-on and enjoyed being out-of-doors for a learning laboratory, and that it allowed them to understand the perspective of foraging for prey actively as a predator. Several students reported that they found it somewhat difficult to see some prey across habitats. Representative remarks from the post-laboratory survey included "*It was really interesting and engaging and I was able to show different principles I learned in class about evolution, and it was interesting to interact with other students in groups in an outdoor lab.*", "*This activity helped me to understand how both predator and prey adapt to their habitats.*", "*I liked going outside for a biology lab since the game was outside so we can understand how nature works in the real world,*" and "*This activity was super engaging, it was cool to put into perspective what its like for predators to hunt for prey and learn about both optimal foraging and industrial melanism and natural selection*".

DISCUSSION

When taken together, the results of this industrial melanism/optimal foraging laboratory indicate that students found it to be engaging, hands-on, and interactive, and gave them practice in thinking like a predator and learning about how prey can blend in with their natural environments. Moreover, students reported that they liked learning outside versus in the laboratory and also working in groups, as they compared the "prey" items at both individual, group, and class levels. This likely enabled them to understand how variation across student "predators" can result in different outcomes. Learning biology outside the classroom, particularly in outdoor labs, can provide unique and engaging experiences for increasing student understanding of the material (Arianti & Aminatun 2018). Therefore, it is likely these types of activities allow students to retain an interest in learning biological principles by connecting key concepts from lecture and laboratories on evolution during a first-year organismal biology course.

Among the most interesting observations in our outdoor field laboratory we noted, include the high level of camouflage specific animal type (moth, snake, or lizard), was readily observable from a short distance of even five-10 meters. In some cases, students developed their "foraging ability" after completing one zone.

We also find it informative that this activity allowed students to investigate within individual and group variation in the number of prey items obtained, with some students obtaining a larger number of "prey" items, while others obtained only a small number of "prey" items. Student feedback included mention of some "prey" items being more camouflaged and in some cases difficult to either see or pick up against specific backgrounds (gray in pine straw, green in green grass, gray moths in gray barked trees, etc.). Also, we observed during one laboratory, a bird picking up a toy snake, then dropping it, showing that care should be taken when performing this activity outdoors and that all "prey" items should be carefully removed from testing environment.

This study shows that teaching the important theory of optimal foraging can be disseminated alongside natural selection and industrial melanism as well as cryptic camouflage of prey relative to predators. Follow-up discussion with student participants showed that students were able to relate to this short outdoor activity and effectively grasped important concepts of predator and prey dynamics. We anticipate this outdoor field activity could be further modified for environmental science majors at various academic levels yet is an effective activity for first-year biology majors. Also, exposure to scientific data collection in these hands-on laboratories should be taught alongside standard lecture delivery of content to reinforce major evolutionary and behavioral ecology within the first-year biology curriculum. These and other types of outdoor education activities can go far in furthering fundamental knowledge and student understanding of theoretical and applied science.

CONCLUSIONS

In conclusion, engaging students in hands-on outdoor activities, which allow them to enter the "mindset" of the predator searching for "prey" alongside developing an understanding of group behavior can concomitantly teach about natural selection, optimal foraging behavior, and industrial melanism, all important biological concepts, which inform evolutionary theory. Therefore, as part of this outdoor activity, students were able to collect data as individuals and as groups, and compare data obtained across groups to understand variation and overwhelmingly reported they liked learning hands-on as part of this laboratory. Future research imparting the importance of real-world simulations carried out by students may go a long way as an effective pedagogical method to teach natural selection to undergraduates.

Recommendations

The primary findings of this study highlight the potential for new approaches to teaching standard examples related to both optimal foraging and industrial melanism. Several improvements could be made to this outdoor learning experience, including adapting the time students spend foraging for "prey", the exact number of items deployed across and within zones, and also the number of students in each group. Further recommendations include the potential to select different types of prey, possibly experimenting with smaller-sized insects, on top or under rocks, or as needed depending on location. Instructors could also ask more follow-up questions based on whether students think working together in groups is more efficient versus working individually, as many animals that forage in groups occur in nature. To this end, the lab could be further modified by allowing some students to forage in one zone as just one individual and not as part of a group to examine the maximum number of prey items one individual could obtain relative to a group working together. This would lend itself well for further discussion on teaching animal behavior theory. We suggest students further visualize their data for which instructors can have either individuals or groups turn in graphs plotting their individual, group or the combined class data. This activity could be improved by including more brightly colored organisms, to teach aposematic or warning coloration, with any of those captured incurring some "costs" to predators. Subsequently, instructors could incorporate an additional predator component, e.g., if a student stays too long in one spot, they themselves become prey, etc. We also recommend instructors routinely check to make sure the paint (gray or green) remains over time, as we noted some degradation as many of these plastic items were used across laboratories. In some cases, the degradation of paint improved the camouflage of prey items. Lastly, we suggest including an additional element of survival into this activity, either for individuals or for groups playing the foraging game, in that each individual needs to obtain a specific number of "prey" items (i.e., a total of three-four per individual; minimum 10 per group, etc.) to survive, either as a group or individual. This could include additional mention of caloric value of larger "prey" items needed for survival. This could further allow students to make connection for survival as a key component of natural selection theory.

Limitations

While we designed this activity to incorporate some random element for placement of similar but not exactly equal numbers of subcategories of animal type, color, and size, i.e., in some cases four or five of each category was deployed, this may have limited our ability to conduct detailed analysis on overall trends. However, as this was not the primary goal of the activity, future labs could standardize deployment, or even adjust the number of each category based on where the zones occur, the overall size of the outdoor area, where instructors perform this outdoor lab. Moreover, standardizing numbers (i.e., either five or 10 of each category) would allow instructors to teach students basic statistical comparisons using equal sample sizes. While this was not a primary goal of this activity, instructors could use our basic approach and cater this activity to their specific course goals and objectives. The three zones included as part of this outdoor activity were not entirely equal in area, which may have biased some ability of student participants to forage for prey. Additional limitations of this outdoor activity include differences in active participation, as we noted some students were more eager than others to actively forage. This could be overcome by making the one-minute foraging activity a slight competition to increase participation across students. This study is limited to first-year undergraduate biology students in the United States but is likely applicable as an outdoor laboratory to many country locations, and also to majors and non-majors in a biology class.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Abraham, J. K., Meir, E., Perry, J., Herron, J. C., Maruca, S., & Stal, D. (2009). Addressing undergraduate student misconceptions about natural selection with interactive simulated laboratory. *Evolution: Education and Outreach, 2*, 393-404. https://doi.org/10.1007/s12052-009-0142-3

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of Research in Science Teaching, 39*(10), 952-978. https://doi.org/10.1002/tea.10053

Arianti, Y., & Animatun, T. (2018). An analysis of outdoor learning towards students' outcomes in learning biology. *Journal of Physics: Conference Series, 1241*, 012061. https://doi.org/10.1088/1742-6596/1241/1/012061

Barber, N. A. (2012). Clay caterpillars: A tool for ecology and evolution laboratories. *The American Biology Teacher, 74*(7), 513-517. https://doi.org/10.1525/abt.2012.74.7.15

Bateman, P. W., Fleming, P. A., & Wolfe, A. K. (2017). A different kind of ecological modeling: The use of clay model organisms to explore predator-prey interactions in vertebrates. *Journal of Zoology, 301*, 251-262. https://doi.org/10.1111/jzo.12415

Bugingo, J. B., Yadav, L. L., Mugisha, I. S., & Mashood, K. K. (2022). Improving teachers' and students' views on nature of science through active instructional approaches: A review of the literature. *Science & Education*. https://doi.org/10.1007/s11191-022-00382-8

Chrouser, W. H. (1975). Outdoor vs. indoor laboratory techniques in teaching biology to prospective elementary teachers. *Journal of Research in Science Teaching, 12*(1), 41-48. https://doi.org/10.1002/tea.3660120107

Church, R., & Hand, S. (1992). Industrial melanism in moths: An interactive computer simulation to demonstrate evolutionary theory. *Journal of Biological Education, 26*(1), 34-36. https://doi.org/10.1080/00219266.1992.9655240

Eisner, T. (1982). For love of nature: Exploration and discovery at biological field stations. *Bioscience, 32*, 321-326. https://doi.org/10.2307/1308848

Fleischner, T. L., Espinoza, R. E., Gerrish, G. A., Greene, H. W., Kimmerer, R. W., Lacey, E. A., Parrish, J. K., Swain, H. M., Trombulak, S. C., Weisberg, S., Winkler, D. W., & Zander, L. (2017). Teaching biology in the field: Importance, challenges, and solutions. *Bioscience, 67*(6), 558-567. https://doi.org/10.1093/biosci/bix036

Fulford, J. M., & Rudge, D. W. (2016). The portrayal of industrial melanism in american college general biology textbooks. *Science & Education, 25*, 547-574.https://doi.org/10.1007/s11190-016-9820-z

Gregory, T.R. (2009). Understanding natural selection: Essential concepts and common misconceptions. *Evolution: Education and Outreach, 2*(2), 156-175. https://doi.org/10.1007/s12052-009-0128-1

Janulaw, A., & Scotchmoor, J. (2011). Clipbirds. Understanding evolution. *University of California Museum of Paleontology*. https://www.ucmp.berkley.edu/education/lessons/clipbirds

Johnson, W. R., & Lark, A. (2018). Evolution in action in the classroom: Engaging students in science practices to investigate and explain evolution by natural selection. *The American Biology Teacher, 80*(2), 92-99. https://doi.org/10.1525/abt.201880.2.92

Leuenberger, W., Larsen, E., Leuenberger, J., & Parry, D. (2019). Predation on plasticine model caterpillars: Engaging high school students using field-based experiential learning and the scientific process. *The American Biology Teacher, 81*(5), 334-339. https://doi.org/10.1525/abt.2019.81.5.334

Majerus, M. E. N. (2009). Industrial Melanism in the peppered moth, *Biston betularia*: An excellent teaching example of Darwinian evolution in action. *Evolution: Education and Outreach, 2*, 63-74. https://doi.org/10.1007/s12052-008-0107-y

Mohammadi, S., Kiriazis, N. M., & Neuman-Lee, L. A. (2020). The natural selection game: Incorporating active learning in evolution criteria for general biology. *The American Biology Teacher, 82*(2), 104-112. https://doi.org/10.1525/abt.2020.82.2.104

Pecor, K. W., Lake, E. C., & Wund, M. A. (2015). Optimal foraging by birds: Experiments for secondary & postsecondary students. *The American Biology Teacher, 77*, 192-197. https://doi.org.10.1525/abt.2015.77.3.7

Pope, D. S., Rounds, C. M., & Clarke-Midura, J. (2017). Testing the effectiveness of two natural selection simulations in the context of a large-enrollment undergraduate laboratory class. *Evolution: Education and Outreach, 10*, 1-16. https://doi.org/10.1186/s12052-017-0067-1

Schwagmeyer, P. L., & Strickler, S. A. (2011). Teaching principles of experimental design while testing optimal foraging theory. *The American Biology Teacher, 73*(4), 238-241. https://doi.org/10.1525/abt.2011.73.4.10

Scott, G. W., Goulder, R., Wheeler, P., Scott, L. J., Tobin, M. L., & Marsham, S. (2012). The value of fieldwork in life and environmental sciences in the context of higher education: A case study in learning about biodiversity. *Journal of Science Education and Technology, 21*, 11-21. https://doi.org/10.1007/s10956-010-9276-x

Thomas, R. L, & Fellowes, M. D. E. (2017). Effectiveness of mobile apps in teaching field-based identification skills. *Journal of Biological Education, 51*(2), 136-143. https://doi.org/10.1080/00219266.2016.1177573

Thomson, J. D. (1980). A simulation of optimal foraging: The nuts and bolts approach. *The American Biology Teacher, 42*(9), 528-533. https://doi.org/10.2307/4447089

Weir, L. K., Barker, M. K., McDonnell, L. M., Schimpf, N. G., Rodela, T. M., & Schulte, P. M. (2019). Small changes, big gains: A curriculum-wide study of teaching practices and student learning in undergraduate biology. *PLoS ONE, 14*(8), e0220900. https://doi.org/10.1371/journal.pone.0220900

Ziadie, M. A., & Andrews, T. C. (2018). Moving evolution education forward: A systematic analysis of literature to identify gaps in collective knowledge for teaching. *CBE-Life Sciences Education, 17*(1), 1-10. https://doi.org/10.1187/cbe.17-08-0190

APPENDIX A

Survey Filled Out by Student Participants During This Outdoor Activity

"Predator Foraging Game"

Survey on Today's Laboratory

A) Was this lab an engaging way to learn about Natural Selection and how predators forage for prey?
Circle one.

Yes No

B) On a scale of 1 to 6, how much did the *Predator Foraging Game* help you to learn about how predators forage and Natural Selection? *Circle One answer below*.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
1	2	3	4	5	6

C) On a scale of 1 to 6, was the *Predator Foraging Game* helpful in learning about how traits/adaptions of *prey* allow them to survive predation? *Circle One answer below*.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
1	2	3	4	5	6

D) *Additional comments* on *The Predator Foraging Game* activity?

(Source: Shem Unger)

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