2018

Integrating Authentic Scientific Research in a Conservation Course-Based Undergraduate Research Experience

Amanda E. Sorensen

Lucia Corral

Jenny M. Dauer

Joseph J. Fontaine

Published April 12, 2018

Integrating Authentic Scientific Research in a Conservation Course–Based Undergraduate Research Experience

Amanda E. Sorensen,* Lucía Corral, Jenny M. Dauer, and Joseph J. Fontaine

Abstract

Course-based undergraduate research experiences (CUREs) have been developed to overcome barriers including students in research. However, there are few examples of CUREs that take place in a conservation and natural resource context with students engaging in field research. Here, we highlight the development of a conservation-focused CURE integrated to a research program, research benefits, student self-assessment of learning, and perception of the CURE. With the additional data, researchers were able to refine species distribution models and facilitate management decisions. Most students reported gains in their scientific skills, felt they had engaged in meaningful, real-world research. In student reflections on how this experience helped clarify their professional intentions, many reported being more likely to enroll in graduate programs and seek employment related to science. Also interesting was all students reported being more likely to talk with friends, family, or the public about wildlife conservation issues after participating, indicating that courses like this can have effects beyond the classroom, empowering students to be advocates and translators of science. Field-based, conservation-focused CUREs can create meaningful conservation and natural resource experiences with authentic scientific teaching practices.

Core Ideas

- Field-based conservation CUREs can engage more students in authentic research.
- Model-based pedagogy in CUREs allows students to grapple with complexity of scientific research.
- Post CURE, student assessment shows science skill gains and clarity in professional goals.
- Post CURE, students are more likely to talk with friends, family, or the public about wildlife conservation.

There is increasing interest across academia to support undergraduate engagement in authentic scientific research (AAAS, 2011; PCAST, 2012). In the conservation and natural resource management fields, numerous reports highlight the importance of engaging students in research experiences to prepare students for the rigors and complexity they will face as professionals (L.H. Newcomb, unpublished, 2004; NRC, 2009; APLU, 2009). In contrast to traditional classroom science experiences where students engage with pre-developed scientific labs that have been assembled for instruction with idealized outcomes through secondhand sources (Songer et al., 2003), authentic engagement in science can allow students to better acquire and apply scientific concepts and skills in a practical and meaningful context (Collins et al., 1988; Robinson et al., 2009). In the context of this article, we define *authentic scientific research experiences* as those where students engage in scientific practices to inform scientific research questions in which there is not already a known answer.

Undergraduate research experiences (hereafter UREs) have been the traditional mode of engaging students in authentic research. Undergraduate research experiences take one of two forms (Bakshi et al., 2016): (1) a student is mentored by a professor or upper-level lab member in an academic research lab over the course of one or more semesters; or (2) a student spends a summer engaged in an intensive research experience. Undergraduate research experiences help students by improving scientific thinking and technical skills, increasing interest in scientific education and scientific careers, and creating a more positive disposition toward the scientific process (Seymour et al., 2004; Laursen et al., 2010; Lopatto and Tobias, 2010; Lopatto, 2007; Brownell et al., 2012; Brownell and Kloser, 2015; Linn et al., 2015). Although there is considerable interest in funding and developing UREs (Lopatto, 2007), student participation is ultimately limited by mentor availability (Bakshi et al., 2016). Because the traditional academic workload limits the number of mentors to oversee UREs, URE positions are generally fewer than the students wishing to participate, making getting a position very competitive (Linn et al., 2015).

Published in Nat. Sci. Educ. 47:180004 (2018)
doi:10.4195/nse2018.02.0004
Received 9 Feb. 2018
Accepted 22 Mar. 2018

A.E. Sorensen and L. Corral, Nebraska Cooperative Fish & Wildlife Research Unit, 3310 Holdrege Street, Room 504, Univ. of Nebraska, Lincoln, NE 68583; J.M. Dauer, School of Natural Resources, Univ. of Nebraska, Lincoln, NE 68583; J.J. Fontaine, US Geological Survey, Nebraska Cooperative Fish & Wildlife Research Unit, Univ. of Nebraska, Lincoln, NE 68583. *Corresponding author (asorensen8@unl.edu).

Abbreviations: CURE, course-based undergraduate research experience; NGSS, Next Generation Science Standards; URE, undergraduate research experience; URSSA, undergraduate research student self-assessment.

A newer approach posited to overcome the barriers of engaging undergraduates in research are course-based undergraduate research experiences (CUREs), which have advantages over traditional UREs as they allow a relatively large number of students to participate in a research experience by incorporating the experience into a course (Linn et al., 2015; Bakshi et al., 2016). Course-based undergraduate research experiences can reduce the out-of-class commitment for students and mentors (Lei and Chuang, 2009) and allow more lower-division students to get exposure to scientific research, as traditional UREs tend to skew toward upper-division students (Linn et al., 2015; Bakshi et al., 2016). Most CUREs are stand-alone opportunities that are not linked to a mentor's research (Brownell and Kloser, 2015; Russell et al., 2015), but there are examples where mentors have successfully incorporated CUREs into ongoing research programs (Miller et al., 2013; Venesky, 2015). Using established research programs improves the ability for institutions to address and overcome many of the logistical and social barriers limiting mentor and student participation in CUREs (Bakshi et al., 2016). By incorporating CUREs into ongoing research, mentors spend less time developing research experiences (Spell et al., 2014), and are better able to provide relevant expertise to participating students, while students benefit from participating in a more comprehensive and applicable research experience (Bakshi et al., 2016). Beyond overcoming logistical barriers, CUREs also benefit research programs by increasing data collection (Dubansky et al., 2013; Porter, 2015), enhancing outreach and community engagement, and developing networks of potential technicians and future collaborators.

Most reported examples of CUREs take place in the context of biological sciences executed in laboratory settings (Bakshi et al., 2016; Dubansky et al., 2013; Miller et al., 2013; Porter, 2015; Venesky, 2015; Wei and Woodin 2011). There are few examples of CUREs integrated into conservation and natural resource sciences and, to the authors' knowledge, no reports of CUREs that take place in a field research setting. Given the emphasis on engaging more students in real-world conservation research (Salafsky et al., 2002; Knight et al., 2008), CUREs may be an important educational tool to meet this goal. Additionally, given the significant benefits of CUREs for scientific research in the biological sciences, it is likely that CUREs can also provide benefits for the conservation and natural resources sciences. However, it is also possible the additional challenges of working in uncontrolled and sometimes distant field sites may present novel barriers to incorporating CUREs in the conservation and natural resource fields.

Course-based undergraduate research experiences are defined by five key dimensions of student engagement (scientific practices, discovery, important work, collaboration, and iteration), making it unique from other undergraduate research experiences (Auchincloss et al., 2014). More specifically, students must:

1. Have the opportunity to engage in multiple *scientific practices* (creating and evaluating models, using the tools of science, designing studies, communicating results, etc.);
2. Address novel scientific questions (*discovery*);
3. Have the opportunity to find relevance of the work outside of the classroom (*important work*);
4. Engage in group work to address research questions (*collaboration*); and
5. Engage in *iterative* scientific practices (repeat or revise aspects of their work).

Creating a CURE that can incorporate students in all five key dimensions may seem more feasible in lab/bench research, as opposed to field research, where there is greater control over the experimental environment and reduced effort in data collection. In field research settings, data collection may be subject to unpredictable environmental conditions, require longer time scales for meaningful sample sizes, and access to field sites may be particularly effortful. Because of the potential additional challenges in field research, meeting all five key dimensions of student engagement may seem difficult over the course of a semester. However, it is equally important that students in conservation and natural resource fields have increased access to authentic research experiences, such as those CUREs provide, as students who are in lab-based disciplines.

Given that CUREs seek to increase student engagement in authentic scientific practices, and interact directly with the complexity of systems, it is important to provide a cognitive framework to support learning. Previous research suggests that students have difficulty grappling with complexity in ecological systems (Jordan et al., 2014). Model-based learning allows students to productively investigate and integrate phenomena at various scales and increase understanding of complex systems (Keen et al., 2005; Wilensky and Reisman, 2006). By generating conceptual models, students can develop a better understanding of complex systems and hypothesize and draw connections to theory (Jordan et al., 2017; Sorensen et al., 2016). Modeling is a fundamental scientific practice (Rosenblueth and Wiener, 1945) and, therefore, should also found science teaching pedagogy (Clement, 2000), particularly in those classes that seek to guide students through authentic research experiences.

By explicitly integrating modeling as the foundation of a CURE, students have a framework for integrating current conceptions with new learning from the research process, emphasizing the iterative nature of science. Iterative model building and refinement fulfills two key dimensions (scientific practices and iteration) of student engagement in a CURE (Auchincloss et al., 2014). Therefore, we posit that CUREs that incorporate model-based instruction may be the best way to integrate the goals of student learning in the context of authentic scientific research.

As CURE is an emerging educational philosophy for which there are few examples of the development and outcomes of CUREs in a conservation and natural resources disciplinary context, we demonstrate the conditions and a framework under which a CURE may be successful and test the benefits to students and mentors. Specifically, we seek to highlight the development of a model-based learning CURE incorporated into an ongoing research program in a conservation class, the benefits to the research program, student self-assessment of learning gains from engaging in the CURE, and student perceptions of their experience. Assessment of student development in scientific epistemology and learning gains are highlighted elsewhere.

CURE DEVELOPMENT

Authentic Institutional Research

Our CURE was developed to integrate into two of the authors long-term research program on species distribution and community dynamics for canids (i.e., dog-like carnivores) in Nebraska. The main goal of the program is to help predict shifts in the patterns of canid species space-use in response to perturbation, and how potential changes in space-use patterns may lead to ecosystem changes. Typical data collection methodology involves camera trapping, where cameras are distributed across the landscape to try to capture images of canids. To get a representative sample of the landscape, cameras need to be distributed widely across a variety of land-use types (i.e., grasslands, agricultural farms, ranches, forests), which presents an issue when most of the land is privately owned, and therefore not readily accessible.

In Nebraska, where our project takes place, approximately 19.6 million hectares (48.4 million acres) (or 98.4% of total land area in the state) is privately owned (see NRCM, 2017). In light of the challenges of sampling a largely private landscape, a CURE that includes student's effort may be a way to increase not only sampling effort, but also access to otherwise unattainable sampling locations. By engaging local students in data collection, research efforts can build on the personal networks of students to develop relationships with family and friends that may provide access to private lands. Our research project lends itself to be modified as a CURE because students are easily trained in the research methods, and there is a great deal of opportunity for students to develop independent research questions that parallel larger project goals. Moreover, the inherent personal connection implicit within the CURE design (i.e., working on family farms or ranches) encourages further buy-in from the students.

Classroom Context

Our class was held at the University of Nebraska-Lincoln and was composed largely of in-state students from the School of Natural Resources. We advertised the course widely and opened it to all class-standings during the fall 2016 semester. There were 6 freshmen, 2 sophomores, 5 juniors, and 10 seniors enrolled in the class, totaling 23 students. The majority of students were natural resources track majors, and approximately half were female.

Implementation

This CURE was broken out into four, 3-hour class meetings over the course of a 16-week semester (see Table 1 for outline of course).

Class Activities

In the first class meeting, students were given an introductory lecture on community ecology, focusing on canid species in Nebraska. As the majority of students were upper-level students majoring in one of the many natural resources tracks, most expressed familiarity with the concepts brought up in lecture. During this first meeting, students developed initial research questions about the presence or absence of canid species on the landscape and conceptual models of the system to help guide and refine their thinking. Modeling underpinned the CURE by providing a formative and summative assessment for instructors (Jordan et al., 2014), a framework for which students could make their ideas about the system explicit and integrate new knowledge, and a mechanism to guide scientific inquiry. To develop their conceptual models, students used Mental Modeler (Gray et al., 2013), which is a free online-tool used to generate models that represent individual and/or group internal conceptions of a system. By generating conceptual models, students can develop a better understanding of complex systems, hypothesize and draw connections to theory (Jordan et al., 2017; Sorensen et al., 2016), and inform their models with the data they collect through their research. The modeling framework we used allowed students to consider their understanding of the

Table 1. General outline of the course, including the topics covered during each meeting, the in-class activities students participated in, and the assignments due for that class.

Class meeting/topic	In-class activity	Assignments due
Class meeting 1		
Background on:	-Develop research question and plan	-Pre-survey to be completed before class 1
-Canid community ecology		-Map of sample location
-Scientific research		
-Experimental design		
Class meeting 2		
-Camera trapping protocol	-Discussion with canid expert on their research plans	-Refined research plan due at end of class 2
-Refining research plans	-In-depth training on using camera trapping equipment	
In between: Students set out camera traps, collect camera traps, and process data. Six-week window between classes 2 and 3 to do this.		
Class meeting 3		
-Statistics	-Data analysis	-All camera trap images processed
Class meeting 4		
-Research presentation	-Student groups gave 15-minute presentations on their work (akin to the style of presentations at scientific conferences)	-Follow up post-survey completed after class 4

system and explicitly consider evidence in support of their ideas. Students were given a demonstration of the Mental Modeler software, and as a group worked through modeling an unrelated phenomenon. To make the models, students were told to think about the different core components that influence swift fox (*Vulpes velox*) populations and represent the relationships between the components by positive or negative connections (red or blue lines) and the strength of the connections (thickness of the line) (see Fig. 1a for example of a student's initial mental model).

Students were then asked to develop research questions that someone might ask based on their models. The remainder of the first class was focused on a background lecture about the primary research students were contributing to and information on the scientific process.

The goal of the second class meeting was to help students refine their research plans, meet with canid ecology experts, and to learn the camera trapping protocol and techniques. For the first half of the second class, swift fox and community ecology researchers talked about how the student lead research was used in tandem with the larger research effort. The researchers also discussed their own research experience and how they develop research plans to ask and answer questions. After a question-and-answer session with the researchers, students received feedback from the experts and instructors on their research plans and were asked to refine their plans based on the feedback and information from the experts. Finally, students were given a presentation on how to use camera trapping equipment following the standardized research protocols, and how to apply the protocols to their individual research plans.

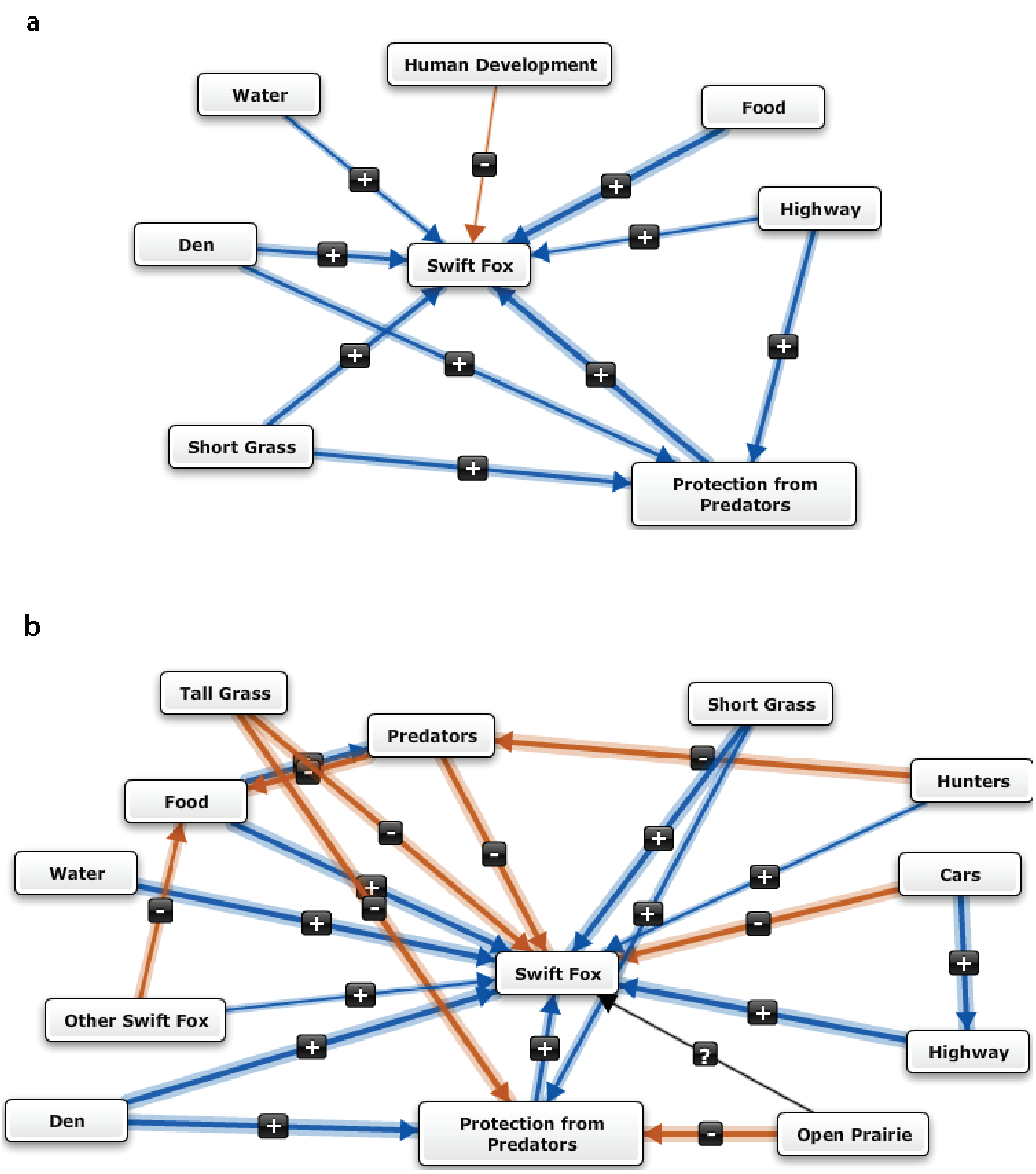

Fig. 1. (a) Example of a student's initial mental model of the swift fox (*Vulpes velox*) system. The model was made in the Mental Modeler software and represents the student's internal representations of why swift fox populations are declining. (b Example of a student's (same student from Fig. 1a) final mental model informed by the course content and the data the class collected and analyzed.

During the 6 weeks between the second and third classes, students were engaged in data collection and processing. Students used the research plans they developed in the first two classes, which were finalized with the instructors during the 6-week interim period. Although the general sampling techniques and protocol were standardized across all students, students adapted the methods to their own unique research endeavors. All students received infrared triggered cameras, a lure, and a field sheet to record various metrics about the camera trap locations including vegetation type, proximity to road, and camera geospatial location. What varied between students was the number of cameras each student received (based on plot size) and where students opted to place the cameras based on their hypotheses of relationships between landscape features and canid presence. Cameras were left in the field for 10 to 14 days. Students then collected the cameras from the field and uploaded the images for processing. Students were given a protocol on camera trap image processing using Timelapse Image Analyzer software (Greenberg and Godin, 2012, 2015). All images with the target canid species were tagged and associated metadata (date, time, location, etc.) uploaded to a broader database. Each student populated a spreadsheet (developed previously by professional scientists for this research) with the information they collected on landscape features at the camera trap locations, which then was integrated with their processed image counts for each species and associated metadata.

The third class meeting occurred after all students had finished collecting and processing their images. A wildlife biologist visited to discuss the nature of scientific endeavors including the value of the students' data in terms of creating scientific models and advancing research questions. The biologist also discussed what is and is not known about swift fox populations and their relationships with other canid species and the habitats in which they occur.

After discussions with the wildlife biologist, students were engaged in data analysis. Students were given a brief presentation of how to do simple statistical functions in Microsoft Office Excel, how statistics are used in scientific research, and guidance on how to interpret their data. Because many of the individual research questions focused on presence–absence of canid species in relationship to different landscape features, individual student data were aggregated for analysis to provide sufficient samples. Students worked in small groups with instructors on their analyses. Later there was a sharing session where each student group shared the results of their analysis with the whole class. Finally, the students were asked to evaluate and potentially modify the mental models they generated in the first class to incorporate new insights from the data analysis session and classroom experiences (See Fig. 1b of a student's final mental model).

Students were asked to evaluate their models for continuity with their data analysis, and if the relationships found from the analyses (their own and the broader class) were represented in their models. For the remainder of the class, students were given a brief lecture on how professional scientific communication is done through presentations at academic conferences. The lecture highlighted the general structure of a research presentation, the purpose of scientific conferences, and a general guide on how to develop a research presentation using Microsoft Office PowerPoint.

The final class meeting culminated in a scientific conference–style presentation session. Student groups presented to the class a 15-minute presentation they developed between the third and fourth class on their research. Included in the audience were wildlife biologists and representatives from the Nebraska Cooperative Fish and Wildlife Research Unit. The students and their guests discussed the students' research findings and their implications for swift fox conservation.

Assessment

Student learning assessments were built into the course in the form of student artifacts from classroom activities (i.e., student models from modeling activities, research plans, written pieces) and the final presentation. These assessments were used to gauge student development in terms of their views of science, understanding of the ecological system, perceptions of environmental issues, and capacity in engaging in the process of scientific research (developing research question, collecting and analyzing data, data interpretation, successful communication through a research presentation, etc.). Additionally, students took part in a self-assessment of their learning gains using the items from the URSSA (Undergraduate Research Student Self-Assessment) instrument (Weston and Laursen, 2015), which provided students an opportunity to reflect on their development following their research experience. The items we used from the URSSA focused on student perceptions of career clarification and refinement, gain in skills, changes in attitudes and behaviors as a researcher, gains in professional socialization, and gains in personal confidence in science.

OUTCOMES

Benefits to Research Program

One semester with 23 students added 14,961 wildlife images (see Fig. 2 for example images) from 18 Nebraska counties to the larger research project.

All of the locations students sampled were areas that professional researchers were unable to access and had not previously sampled. With the additional data, researchers were able to further refine species distribution models for swift fox and other canid species, get a better understanding of Nebraska's canid community composition, and inform management decisions. In a state that is over 98% privately owned, the important long-term and large-scale aspect of the canid project would not be feasible without public engagement; hence, a key part of the research is to incorporate the public in the scientific research, in this case by working closely with local students who help both by providing access to private land for sampling and collecting data.

Student Self-Assessment of Learning Gains

Twenty-one of the 23 students completed the post-class survey. From the self-assessment survey students reported their experience as largely beneficial. Most students reported either a good or great gain in their scientific skills as a result of their participation across the various constructs (Fig. 3a). Additionally, students reported that they understood the relevance of the research to their coursework. In terms of perceptions of gains in confidence and integration to the culture of science, most students

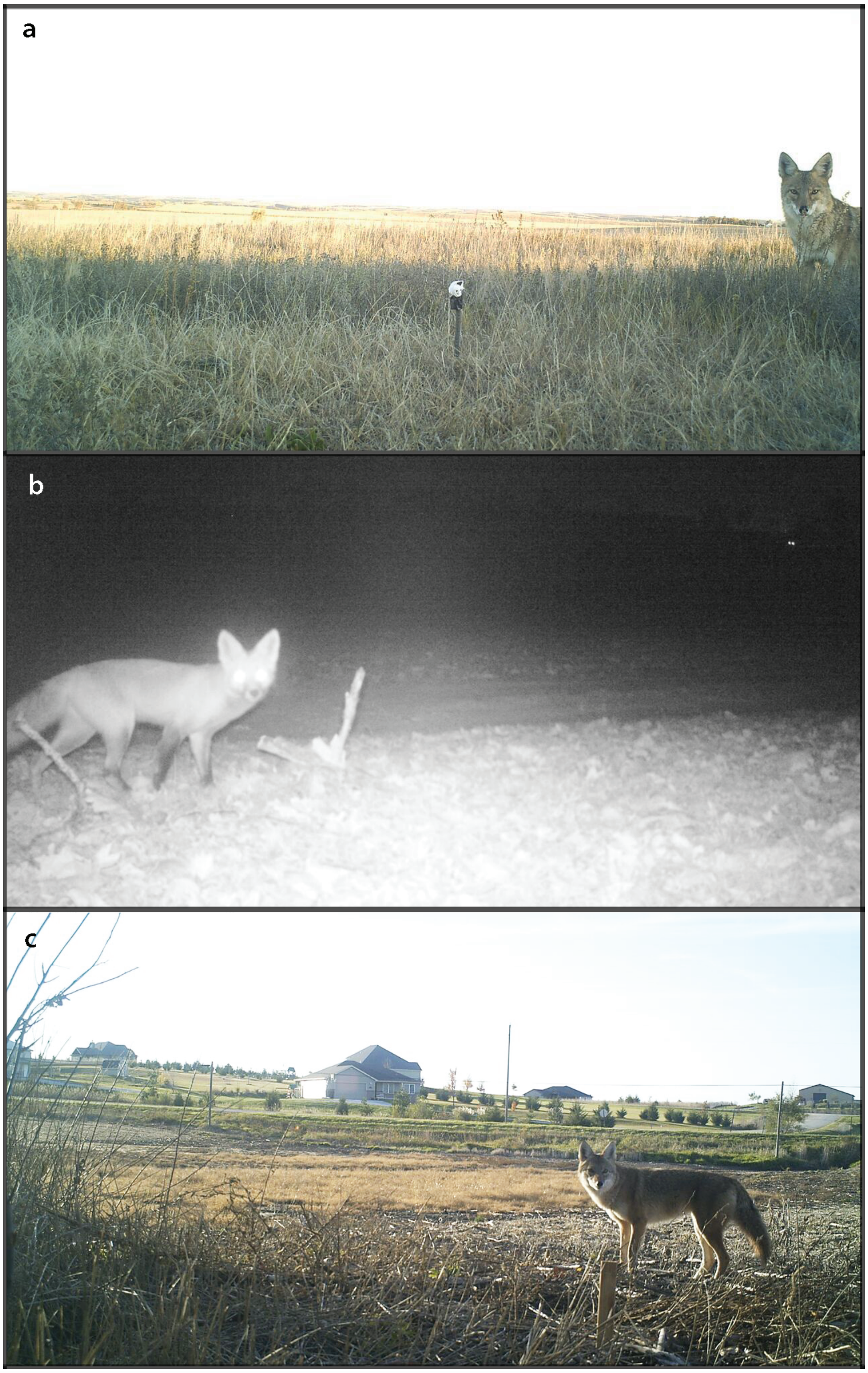

Fig. 2. Example of images captured by students on camera traps. (a) coyote (*Canis latrans*), (b) red fox (*Vulpes vulpes*), (c) coyote.

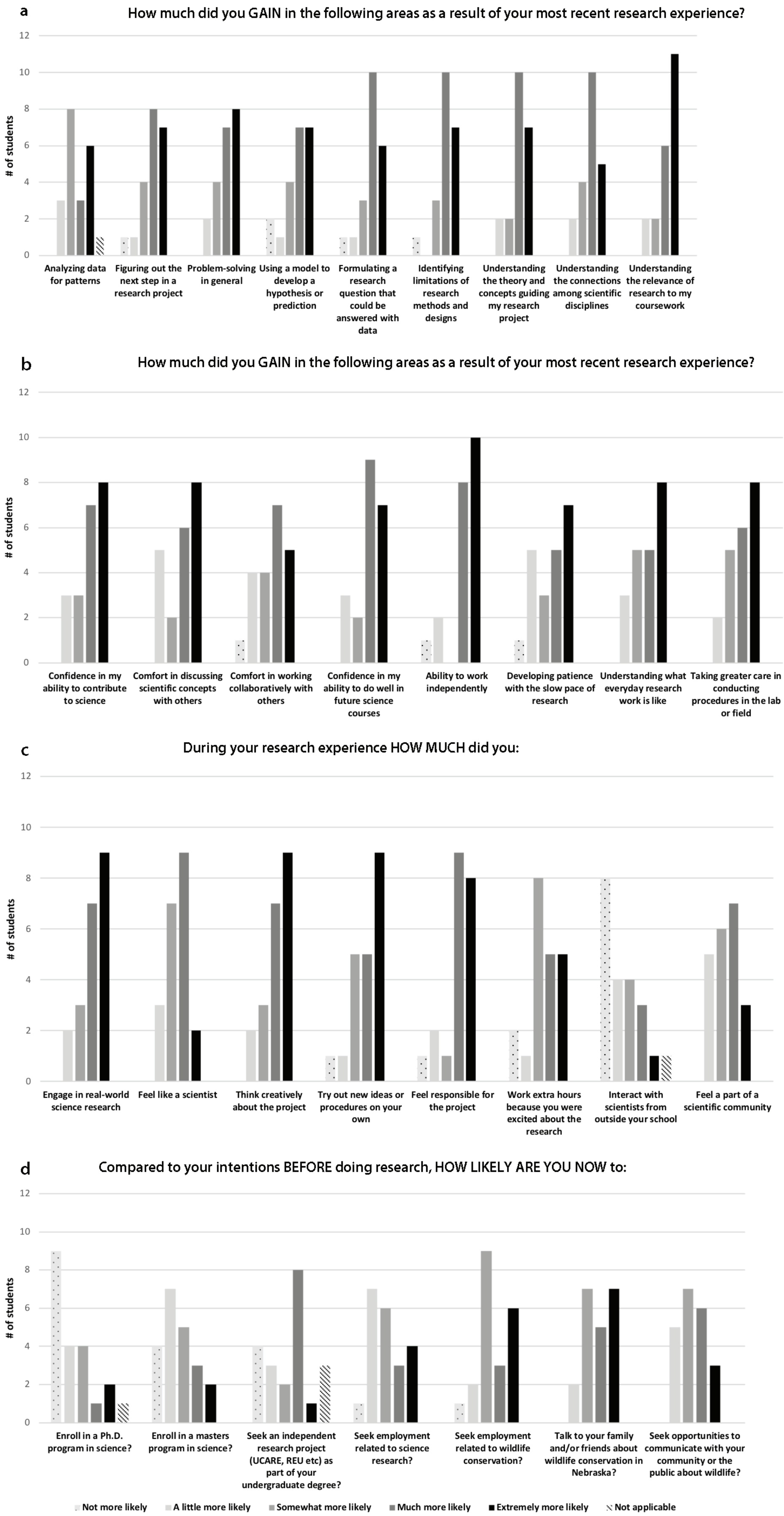

Fig. 3. Responses to the URSSA survey students filled out after the course ended (n = 21).

reported good or great gains (Fig. 3b). In particular, 18 out of 21 students reported good or great gains in their ability to work independently. In addition, most students felt that they had engaged in real-world scientific research, were able to think creatively about the project, and could try out new ideas on their own (Fig. 3c). Although our project did not offer many opportunities for students to interact with scientists outside of the institution, the students considered themselves to be part of the broader scientific community. Finally, in student reflections on how their experience helped clarify their professional intentions beyond the class, most students reported being more likely to enroll in a graduate program and seek employment related to science and wildlife conservation (Fig. 3d). Although most of the seniors in the class did not state they would be more likely to participate in an independent research project as an undergraduate student, likely because they were set for graduation, 10 of 11 non-senior students reported being more likely to seek an independent research project as a part of their undergraduate degree. Also interesting is that all students reported being more likely to talk with friends, family, or the general public about wildlife conservation issues after participating in the CURE.

Student Perceptions of CURE

Beyond benefits to the professional science from the data collection efforts of the course, students who participated expressed enjoyment and desire to engage further. Of the 11 students who provided detailed written responses about their course experiences, 10 had positive comments about their experiences. The 11th student wrote a neutral comment about course logistics (expressing the desire for the class meeting time to be earlier in the day). One student, for example, talked about the uniqueness of the course, saying "I did really enjoy it [the class]. It was a good opportunity for freshman to get hands-on experience in an upper level class and actually have a class to look forward to throughout the semester..."

Similar sentiments were shared by the other students who wrote in responses, regardless of their academic status, suggesting that a course designed such as ours is accessible and valuable to students at all levels. Other students expressed the desire to further engage in research, noting "I really enjoyed the course, looking back it would be nice to set cameras out twice to compare capture methods and gather more data." This student is discussing the outcomes of the work much like a scientist would. In this case, the student is thinking about adding another (temporal) dimension of data collection to see how it might influence the relationships they found. Without any prompting from instructors, this student demonstrates the iterative nature of scientific research.

Finally, many students also expressed enjoying the CURE over other scientific courses because of the authentic nature of their engagement in the scientific process. In this vein, one student said of the course, "It was really rewarding to be able to hypothesize where canids/any species would be found on a property, set out to answer the question yourself, and actually find out you were right." It is clear from student feedback that this type of course was a novel and highly engaging experience for many.

DISCUSSION

It is clear that CUREs can provide benefits for students and authentic scientific research endeavors alike. We demonstrated that CUREs in the classroom may be a way to overcome research challenges, in our case by directly engaging local students in collecting data on private lands. Similar to citizen science and other public participatory scientific research, CUREs can capitalize on the unique contribution of the individuals participating in the research. We observed that our CURE filled a similar niche as citizen science might in terms of data contributions to ongoing research. In this way, CUREs can broaden the scope of data collection and help meet scientific needs much like citizen science (Dickinson et al., 2010). We would not characterize our CURE as citizen science, though, because of the nature of student participation for course credit (students are a captive audience), and the primary goal of participation was educational. In citizen science projects, the primary goal of participation is data contribution to answer scientific questions, often paired with secondary goals such as education or enjoyment (Cornell University, 2018). However, the protocol developed for our CURE could be successfully modified for a broader public engagement or citizen science program. Indeed, similar projects such as eMammal rely on a distributed volunteer network to manage and set up camera traps (McShea et al., 2016). The ability for CUREs and citizen science contributions to meaningfully contribute to research is important, considering that conservation research is often limited by a number of factors including access to land, labor force, and time.

Beyond the benefits to ongoing scientific research, CUREs also provide greater access to research experiences for students (Auchincloss et al., 2014), conferring the benefits of research experiences to a wider group of students than can traditionally be reached. As CUREs can be offered to students at all levels, there is the potential for a CURE to shift a students' educational and career trajectories earlier in their education, as opposed to finding out they wish to change majors after research opportunities that too often are only provided to upper-level students (Rodenbusch et al., 2016). As was echoed by some of our students, despite being early on in their education, they expressed enjoyment and saw great value from the opportunity to do research, which may translate to higher graduation rates of students in STEM fields (Rodenbusch et al., 2016).

Another interesting outcome was that students reported greater interest in talking to family, friends, and the public about issues connected to this class. This finding suggests that CUREs can have effects beyond the classroom, empowering students to be advocates and translators of science. By allowing students to conduct research in their own backyards, conservation and natural resources field–based CUREs can connect students to their communities and instill a greater sense of relevance and importance of the research. Studies of place-based education (where education is grounded in the local community) find that students are more engaged in their courses, more interested in their local communities, and show greater academic achievement (Powers, 2004). Further work is needed to investigate how participation in field-based CUREs translates to long-term advocacy and behavior toward conservation issues, and the broader impacts on conservation efforts within local communities.

As more educational research emphasizes the importance of integrating authentic science into the formal classroom (Songer et al., 2003), it is clear that CUREs can play a role in creating such opportunities. Faculty often fail to teach students how to think critically and engage scientifically (D'Avanzo, 2008). If our goal as educators is to have students engage and think as scientists, we should design courses and provide support for development of cognitive processes and structures (Jordan et al., 2017). Aligning authentic scientific research practices, both the physical skills (i.e., field work, collecting data, analyzing data) and cognitive epistemic practices (i.e., theory building, modeling, evaluating evidence, and refining ideas), is critical for future improvement in scientific teaching (National Research Council, 2013). Indeed, CUREs that incorporate model-based instruction, as we highlighted here, may be a pathway to integrate the goals of student learning in the context of authentic scientific research. Additionally, corroborating other work (Jordan et al., 2017), we found that modeling was a useful tool to help organize student thinking, communicate, tie data to theory, and generally think scientifically. Model-based CURE science instruction also has implications for student motivation and engagement, as it avoids the repetition of traditional science curriculum that often does not provide enough engagement or challenge for students (Osborne and Collins, 2001). In future work, we hope to characterize how model-based learning practices embedded into a CURE facilitate student learning and impact student interest in and future plans to engage in scientific research. The CURE design we have highlighted here could be translated to other conservation and natural resource programs interested in providing more opportunities for students to participate in authentic scientific research experiences.

ACKNOWLEDGMENTS

We would like to thank C. Helmke, T. Frink, S. Wilson, D. Betz, and J. Carroll for their help in implementing the course, and D. Bhattacharya and two anonymous reviewers for their thoughtful comments. Funding was received from the Nebraska Environmental Trust grant 15-202-3 and Federal Aid in Wildlife Restoration project T-86-R, administered by the Nebraska Game and Parks Commission. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US government. The Nebraska Cooperative Fish and Wildlife Research Unit is supported by a cooperative agreement among the US Geological Survey, the Nebraska Game and Parks Commission, the University of Nebraska, the US Fish and Wildlife Service, and the Wildlife Management Institute.

REFERENCES

American Association for the Advancement of Science. 2011. Vision and change in undergraduate biology education: A call to action. AAAS, Washington, DC.

Association of Public and Land-Grant Universities. 2009. Human capacity development: The road to global competitiveness and leadership in food, agriculture, natural resources, and related sciences (FANRRS). APLU, Washington, DC.

Auchincloss, L.C., S.L. Laursen, J.L. Branchaw, K. Eagan, M. Graham, D.I. Hanauer, G. Lawrie, C.M. McLinn, N. Pelaez, S. Rowland, et al. 2014. Assessment of course-based undergraduate research experiences: A meeting report. CBE Life Sci. Educ. 13:29–40. doi:10.1187/cbe.14-01-0004

Bakshi, A., L.E. Patrick, and E.W. Wischusen. 2016. A framework for implementing course-based undergraduate research experiences (CUREs) in freshman biology labs. Am. Biol. Teach. 78:448–455. doi:10.1525/abt.2016.78.6.448

Brownell, S.E., and M.J. Kloser. 2015. Toward a conceptual framework for measuring the effectiveness of course-based undergraduate research experiences in undergraduate biology. Stud. High. Educ. 40:525–544. doi:10.1080/03075079.2015.1004234

Brownell, S.E., M.J. Kloser, T. Fukami, and R. Shavelson. 2012. Undergraduate biology lab courses: Comparing the impact of traditionally based 'cookbook' and authentic research-based courses on student lab experiences. J. Coll. Sci. Teach. 41:36–45.

Clement, J. 2000. Model based learning as a key research area for science education. Int. J. Sci. Educ. 22:1041–1053. doi:10.1080/095006900416901

Collins, A., J.S. Brown, and S.E. Newman. 1988. Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. Thinking: J. Philos. Child. 8(1):2–10.

Cornell University. 2018. What is citizen science and PPSR? The Cornell Lab of Ornithology, Cornell Univ., Ithaca, NY. http://www.birds.cornell.edu/citscitoolkit/about/defining-citizen-science/ (accessed 2 Mar. 2018).

D'Avanzo, C. 2008. Research on learning: Potential for improving college ecology teaching. Front. Ecol. Environ 1:533–540. doi:10.1890/1540-9295(2003)001[0533:ROLPFI]2.0.CO;2

Dickinson, J.L., B. Zuckerberg, and D.N. Bonter. 2010. Citizen science as an ecological research tool: Challenges and benefits. Annu. Rev. Ecol. Evol. Syst. 41:149–172. doi:10.1146/annurev-ecolsys-102209-144636

Dubansky, B.D., A. Whitehead, J.T. Miller, C.D. Rice, and F. Galvez. 2013. Multitissue molecular, genomic, and developmental effects of the Deepwater Horizon oil spill on resident gulf killifish (*Fundulus grandis*). Environ. Sci. Technol. 47:5074–5082. doi:10.1021/es400458p

Gray, S.A., S. Gray, L. Cox, and S. Henly-Shepard. 2013. Mental modeler: A fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. In: Proceedings of the 46th Hawaii International Conference on System Sciences (HICSS). HICSS, Univ. of Hawaii at Manoa, Honolulu, HI. p. 965–973. doi:10.1109/HICSS.2013.399

Greenberg, S., and T. Godin. 2012. Timelapse image analysis manual. Tech. Rep. 2012-1028-11. Dep. of Computer Science, University of Calgary, Calgary, AB, Canada. http://grouplab.cpsc.ucalgary.ca/cookbook/index.php/Demos/TimelapseCoder (accessed 1 Oct. 2017).

Greenberg, S., and T. Godin. 2015. A tool supporting the extraction of angling effort data from remote camera images. Fisheries Magazine 40:276–287. doi:10.1080/03632415.2015.1038380

Jordan, R.C., A.E. Sorensen, and C. Hmelo-Silver. 2014. A conceptual representation to support ecological systems learning. Nat. Sci. Educ. 43:141–146. doi:10.4195/nse2014.09.0019

Jordan, R.C., S. Gray, A.E. Sorensen, S. Pasewark, S. Sinha, and C.E. Hmelo-Silver. 2017. Modeling with a conceptual representation: Is it necessary? Does it Work? Frontiers in ICT 4:7. doi:10.3389/fict.2017.00007

Keen, M., V.A. Brown, and R. Dyball. 2005. Fostering ecoliteracy through model-based instruction. Front. Ecol. Environ 12:138–139.

Knight, A.T., R.M. Cowling, M. Rouget, A. Balmford, A.T. Lombard, and B.M. Campbell. 2008. Knowing but not doing: Selecting priority conservation areas and the research–implementation gap. Conserv. Biol. 22(3):610–617.

Laursen, S., A.-B. Hunter, E. Seymour, H. Thiry, and G. Melton. 2010. Undergraduate research in the sciences: Engaging students in real science. Wiley, San Francisco, CA.

Lei, S.A., and N.K. Chuang. 2009. Undergraduate research assistantship: A comparison of benefits and costs from faculty and students' perspectives. Education 130(2):232–241.

Linn, M.C., E. Palmer, A. Baranger, E. Gerard, and E. Stone. 2015. Undergraduate research experiences: Impacts and opportunities. Science 347:1261757. doi:10.1126/science.1261757

Lopatto, D. 2007. Undergraduate research experiences support science career decisions and active learning. CBE Life Sci. Educ. 6:297–306. doi:10.1187/cbe.07-06-0039

Lopatto, D., and S. Tobias. 2010. Science in solution: The impact of undergraduate research on student learning. Council on Undergraduate Research, Washington, DC.

McShea, W.J., T. Forrester, R. Costello, Z. He, and R. Kays. 2016. Volunteer-run cameras as distributed sensors for macrosystem mammal research. Landsc. Ecol. 31:55–66. doi:10.1007/s10980-015-0262-9

Miller, C.W., J. Hamel, K.D. Holmes, W.L. Helmey-Hartman, and D. Lopatto. 2013. Extending your research team: Learning benefits when a laboratory partners with a classroom. Bioscience 63:754–762. doi:10.1093/bioscience/63.9.754

National Research Council. 2009. Transforming agricultural education for a changing world. National Academies Press, Washington, DC. doi:10.17226/12602

National Research Council. 2013. Next generation science standards: For states, by states. National Academies Press, Washington, DC. doi:10.17226/18290.

Natural Resources Council of Maine. 2017. Public land ownership by state. NRCM, Augusta, ME. https://www.nrcm.org/documents/publiclandownership.pdf (accessed 12 Nov. 2017).

Osborne, J.F., and S. Collins. 2001. Pupils' views of the role and value of the science curriculum: A focus-group study. Int. J. Sci. Educ. 23:441–467. doi:10.1080/09500690010006518

President's Council of Advisors on Science and Technology (PCAST). 2012. Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. US Gov. Office of Science and Technology, Washington, DC.

Porter, D.T. 2015. Distribution and female reproductive state differences in orexigenic and anorexigenic neurons in the brain of the mouthbrooding African cichlid fish, *Astatotilapia burtoni*. M.S. thesis. Louisiana State University, Baton Rouge, LA.

Powers, A.L. 2004. An evaluation of four place-based education programs. J. Environ. Educ. 35:17–32. doi:10.3200/JOEE.35.4.17-32

Robinson, J.M., A.F. Wise, and T.M. Duffy. 2009. Authentic design and collaboration: Involving university faculty as clients in project-based learning technology design courses In: C. DiGiano and S. Goldman, editors, Educating learning technology designers. Routledge, NY. p. 80–100.

Rodenbusch, S.E., P.R. Hernandez, S.L. Simmons, and E.L. Dolan. 2016. Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. CBE Life Sci. Educ. 15:ar20. doi:10.1187/cbe.16-03-0117

Rosenblueth, A., and N. Wiener. 1945. The role of models in science. Philos. Sci. 12:316–321. doi:10.1086/286874

Russell, J.E., A.R. D'Costa, C. Runck, D.W. Barnes, A.L. Barrera, J. Hurst-Kennedy, and R. Haining. 2015. Bridging the undergraduate curriculum using an integrated course-embedded undergraduate research experience (ICURE). CBE Life Sci. Educ. 14:ar4. doi:10.1187/cbe.14-09-0151

Salafsky, N., R. Margoluis, K.H. Redford, and J.G. Robinson. 2002. Improving the practice of conservation: A conceptual framework and research agenda for conservation science. Conserv. Biol. 16:1469–1479.

Seymour, E., A.-B. Hunter, S.L. Laursen, and T. DeAntoni. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. Sci. Educ. 88:493–534. doi:10.1002/sce.10131

Spell, R.M., J.A. Guinan, K.R. Miller, and C.W. Beck. 2014. Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. CBE Life Sci. Educ. 13:102–110. doi:10.1187/cbe.13-08-0169

Songer, N.B., H.S. Lee, and S. McDonald. 2003. Research towards an expanded understanding of inquiry science beyond one idealized standard. Sci. Educ. 87:490–516. doi:10.1002/sce.10085

Sorensen, A.E., R.C. Jordan, R. Shwom, D. Ebert-May, C. Isenhour, A.M. McCright, and J.M. Robinson. 2016. Model-based reasoning to foster environmental and socio-scientific literacy in higher education. J. Environ. Stud. Sci. 6:287–294. doi:10.1007/s13412-015-0352-7

Venesky, M. 2015. Guidelines for class projects as publishable research. Liberal Arts Ecologists. https://theliberalartsecologists.wordpress.com/2015/05/14/guidelines-forclass-projects-as-publishable-research/2015 (accessed 1 Oct. 2017).

Wilensky, U., and K. Reisman. 2006. Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—an embodied modeling approach. Cogn. Instr. 24:171–209. doi:10.1207/s1532690xci2402_1

Wei, C.A., and T. Woodin. 2011. Undergraduate research experiences in biology: Alternatives to the apprenticeship model. CBE Life Sci. Educ. 10:123–131. doi:10.1187/cbe.11-03-0028

Weston, T.J., and S.L. Laursen. 2015. The Undergraduate Research Student Self-Assessment (URSSA): Validation for use in program evaluation. CBE Life Sci. Educ. 14:ar33. doi:10.1187/cbe.14-11-0206