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Sensing in Animals and Robots: Collaborative, Transdisciplinary Learning in an Undergraduate Science Course

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ABSTRACT
Transdisciplinary learning—where students develop and apply knowledge from multiple disciplines to solve open-ended problems—is necessary to prepare students for the most pressing real-world problems. Because transdisciplinary education often requires reimagining the content and design of undergraduate science courses, it can be a challenge for instructors to envision how such work might take place. In this article, we share an example of an undergraduate course developed at the intersection of animal sensory biology and robotics engineering. Students in the course developed knowledge from both disciplines to design a robot that could mimic the sensory behaviors of some animals to achieve a predetermined task. We share examples of students' work in the course and evidence of how students' perceptions of science and engineering changed throughout their participation in the course. Additionally, we describe how we adapted a hybrid model of collaboration that made it feasible for students to work together on an open-ended project requiring access to robotics equipment during the COVID-19 pandemic. This course can serve as a model for instructors working to incorporate more interdisciplinary or transdisciplinary perspectives into existing science courses.

KEYWORDS
Transdisciplinary learning; Animal sensory biology; Robotics; Engineering; STEM; Collaboration; Interdisciplinary learning

Transdisciplinary teaching and learning should prepare learners to draw on the knowledge and skills of multiple disciplines to solve authentic, open-ended problems (Vasquez, 2015). This approach is believed to have the highest potential for solving the most pressing real-world problems (National Research Council, 2012), which means there is an impetus for university science courses to incorporate more interdisciplinary and transdisciplinary learning opportunities. However, learning opportunities that are truly transdisciplinary can be difficult to create for multiple reasons, one of which is that the structure of many postsecondary courses does not allow the time or flexibility for students to engage in solving more open-ended problems.

In this article, we describe how faculty from biology and engineering implemented a transdisciplinary university course and a project in which undergraduate students collaborated to design robots whose behaviors modeled the sensory behaviors of different animals in the natural world. We answer the following question: "How were students' perceptions of problem-solving, collaboration, and engineering shaped by their participation in the transdisciplinary course?" We also describe how the learning environment adapted to the constraints of remote, in-person, and hybrid learning in a way that preserved students' opportunities for problem-solving and collaboration. Our example provides a model for how students can learn to integrate knowledge of animal sensory biology and robotics engineering to solve open-ended problems. Additionally, we illustrate how students can engage in collaborative work with robots in ways that positively shape their perceptions of engineering, problem-solving, and collaboration.

It has become commonplace to study and describe the control of animal movements using techniques and terminology borrowed from engineering (see, e.g., Shöne, 1984). The advent of this approach in the 1960s (e.g., Wiener, 1961) brought about a new, more rigorous look inside the "black box" of animal behavior by applying quantitative theories of guidance and control. It created a direct analogy between animals and machines so that within a single paradigm,

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animals and machines are comprehended and studied within the same sensory signal processing and behavioral control frameworks (e.g., Manoonpong & Tetzlaff, 2018). This unified view creates a natural space in which practitioners of biology and robotics can meet, communicate, and inspire one another. It is also perfectly positioned, and sufficiently fleshed out, to form an ideal area for introducing transdisciplinary thinking and learning.

The Course

The project team developed an undergraduate course called Sensing in Animals and Robots. The course was created as part of an effort to improve students' learning experiences at the intersection of biology and engineering. The larger project includes a 3-week summer program in which local high school students (and teachers) learn about the interface of biology and engineering through biology labs and robotics challenges. The undergraduate course is designed as a "stackable experience" with the summer program. Students who have completed the summer program extend their knowledge and skills through more advanced labs and robotics work. Students who have not participated in the summer program can take the undergraduate course as a first introduction to the integration of biology and engineering. The course was approved for the College Credit Plus program, a state initiative through which high school students can take courses for college credit at no cost (Ohio Department of Education Department of Higher Education, 2020).

The learning outcomes of Sensing in Animals and Robots include knowledge and skills related to sensory biology as well as robotics. Through their participation in the course, students describe the properties of sensory stimuli and describe how biological and human-made sensors detect and process stimuli. While learning about these sensory mechanisms, students compare human-made sensors with biological sensory organs and describe the limitations of human-made sensors. Students learn examples of how biological principles have been adapted to robot design as well as how robots have been used to test hypotheses about animal behavior. In addition to the specific learning outcomes, the course attends to broader transferable skills such as critical thinking and collaboration, as well as the engineering design process. The culminating project of the course is to design a robot that mimics sensory-guided behaviors of animals.

Sensing in Animals and Robots was designed with no prerequisites. It has been taken by students majoring in biological sciences, neuroscience, and engineering, in addition to high school students who take the course for college credit. Time in class is divided between lectures and labs, which allows us to ensure that all students have enough knowledge of biology and engineering to draw on both fields for the final project. Early in the course, labs are mostly aimed at reinforcing the biology concepts that are introduced through lectures. Students also develop a range of programming skills to make a robot move and to read, and respond to, data from different electronic sensors. In the second half of the course, students work collaboratively to propose and implement a final project that incorporates and extends their learning throughout the semester.

The Culminating Project: Animal-Inspired Robots

The culminating project of the Sensing in Animals and Robots course is to develop a biologically inspired robot and to create a presentation about how its design is informed by an animal's (or animals') sensory behaviors. Working in pairs or groups of three, students extend what they learn in class by doing library research about how different animals use one or more senses to guide their behavior and decision-making. Throughout the semester, students learn to use vision, sonar, auditory, heat, and whisker sensors in coordination with learning about the corresponding sensory systems used by animals in the natural world. In their final presentation, students share the findings of their research and exhibit their robot and its behavior through an "arena" that includes a set of obstacles. Each group of students uses an iRobot Create® 2 robot (Figure 1).

The robotics challenge consists of the following components:

1. The robot has to start from a location, which is its "home."
2. The robot has to move into the arena and, using its sensors, find two or three objects in the arena.
3. The robot has to correctly identify an object by one or more properties (e.g., color, loudness, size).
4. After finding and identifying the objects, the robot has to return home.

One pair of students in spring 2021, for example, designed a robot that used a color sensor to approach a blue target and a sonar sensor to avoid obstacles in its path. In their final presentation, the pair described

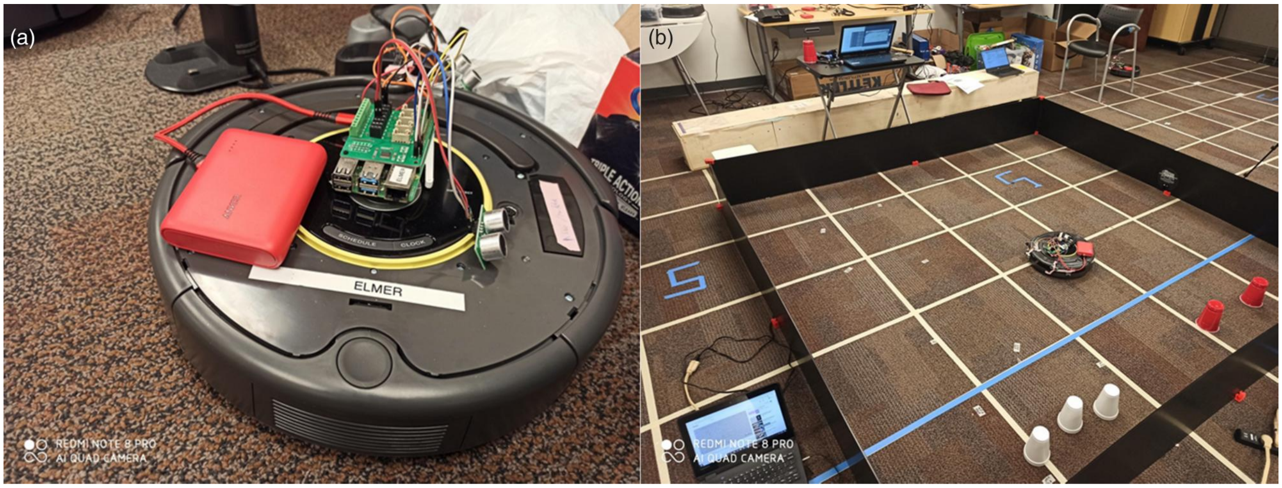

Figure 1. An iRobot Create® 2 Robot and the lab setup.
Note. Panel 1a: An iRobot Create 2 robot equipped with a sonar sensor (right) and a battery (left). Panel 1b: A robot in an "arena."

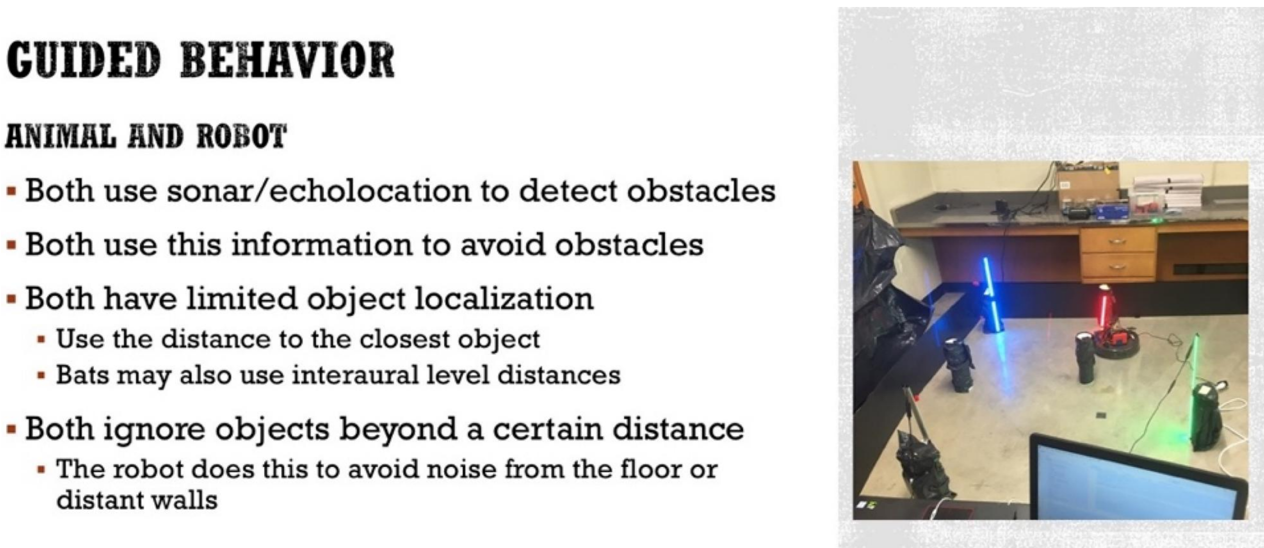

Figure 2. An excerpt of a student presentation relating bats' use of sonar to their robot.

how the robot's activities mimicked the use of sonar by bats, including the affordances and constraints of sonar as a means of object localization (Figure 2). The students incorporated what they had learned about bats' use of sonar to inform the behavior they programmed for their robot. For example, after learning that bats ignore objects beyond a certain distance, the students included code for their robot to do the same so that it could disregard readings from walls or other distant objects. Additionally, their learning about bats helped them anticipate and account for the limitations of their robot, namely with respect to the specificity with which it could locate obstacles.

The final project, which students develop and refine gradually over the second half of the semester, is a key component of the transdisciplinary nature of the course. The project is an authentic task in that students identify a challenge (in the form of obstacles) and then decide how to respond to that challenge by adapting sensory-guided behaviors of animals for use in their robots. The project requires students to apply knowledge of biological sensory systems and robotics engineering, and it is a simplified version of the work of researchers at the intersection of sensory biology and engineering (e.g., Astley et al., 2020; Vanderelst et al., 2016). Students' work on their final project allows them to integrate the two fields of knowledge in order to define and solve a problem of their choosing, and this component is where the course shifts from an interdisciplinary effort to teach biology and engineering in relation to one another to a transdisciplinary effort for students to take on an authentic, real-world task.

The Sensing in Animals and Robots course was specifically framed around the field of sensory biology and its applications to robotics engineering. Similar connections could be made across other subfields of biology or other natural sciences. In the summer program, for example, we implemented an activity in which students learned about fish biomechanics and modified a robotic fish based on their knowledge of the mechanics of fish that contribute to swimming speed.

The robotics challenge also incorporated an engineering design process. The NGSS Lead States (2013, pp. 129–130) characterized engineering design as a process of defining an engineering problem, developing possible solutions, and then optimizing a design solution. Because of the open nature of the task, students in the course needed to determine the parameters of their work according to the criteria of the task, the constraints of time and equipment, and the extent of their own knowledge. Based on these decisions, students worked collaboratively to determine how to solve their challenge and optimize that solution. The engineering design process is a useful way to make science learning more authentic and relevant to undergraduate students while also improving their learning of science content (Radloff et al., 2019; Turner & Hoffman, 2018). The use of educational robots can be thought of as a complement to the engineering design process. The feedback provided by a robot, based on a user's inputs, in real time has been shown to contribute to students' development of problem-solving skills in different contexts (Barker & Ansorge, 2007; Blanchard et al., 2010). While there are many examples of the use of robotics at the undergraduate level to introduce students to engineering design more broadly (e.g., Kaya et al., 2017; Martinez Ortiz et al., 2015), with this course we have leveraged the use of robots as a means of incorporating transdisciplinary problem-solving and learning into the curriculum.

Preserving Students' Collaborative Learning Through Remote Instruction

The onset of the COVID-19 pandemic in 2020 brought massive interruptions to students' opportunities to learn in more traditionally defined classroom settings (Gibson & Shelton, 2021). In spring 2020, Sensing in Animals and Robots was scheduled to meet in person once per week for 3 hours. Courses shifted to entirely remote instruction shortly after the instructors introduced the guidelines for the final project. In addition to the universal challenges of supporting students' learning and general well-being during this time, this course had a unique challenge associated with the use of the robots. Each pair or group of students shared one robot, which was stored on campus and required substantial floor space to maneuver. It would not have been feasible to have students "check out" the robots to use at home for the last half of the semester, so the project team had to develop a way for students to continue working on their robots remotely. Figure 3a illustrates the model that we used.

As illustrated in Figure 3a, students were introduced to the use of remote desktop software so that they could log in from their home computers to a computer on campus that was connected to their robot. During their work time, a group of students would set up a call and connect via remote desktop to the same campus computer. One instructor could be in the room with the robot and also connected to the pair of students via cell phone. The setup represented in Figure 3a accomplished two important requirements to make the final project viable: First, students scheduled synchronous meetings with course instructors to work and get feedback on their efforts. Second, the instructor in the room was able to move the robot or adjust sensors as necessary, since students had no in-person interaction with their robots.

The model in Figure 3a was a feasible option to preserve students' opportunities to design and create

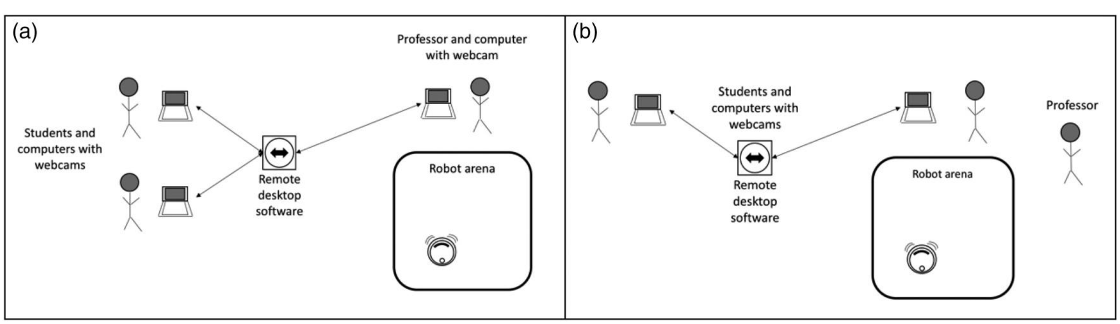

Figure 3. Collaboration models for pair work during the 2 semesters of the course.
Note. Panel 3a: Spring 2020. Panel 3b: Spring 2021.

robotic models when class was fully remote, but it had limitations. Primarily, students were not able to tinker with, adjust, or move their robots independently. The course instructors became integral to the work of each pair of students because they had to constantly be present to position the webcam so students could see the robot and to move the robots and make adjustments to sensors at students' requests. As a consequence, students may have had fewer opportunities than they otherwise would have to solve problems with their peers. In spring 2021, when hybrid options were available with safety measures in place, we revised our collaboration model so that students from each group took turns coming to campus (Figure 3b). Each group of students connected during their work time via video call and remote desktop software. The primary difference was that students could take turns being in the room with the robot. Because each robot arena covered more than 4 square meters, and therefore the classroom space was quite large, it was possible to accommodate half of the class at a time in person. The collaboration model illustrated in Figure 3b made an important change to the role of the course instructors in the work of each pair of students. Students had more autonomy, and instructors could move among different pairs of students as needed.

Analysis of Student Survey Responses

Part of our project involved surveying students at the beginning and end of each semester to document their perceptions of science, technology, engineering, and mathematics (STEM) fields and 21st-century learning practices such as collaboration and problem-solving (see Table 1 for a subset of survey prompts). In each semester, students completed both surveys electronically; the pre-survey was administered and completed by the second week of class, and the post-survey was completed after students' final project presentation. Students were provided with a list of statements to which they could indicate their agreement on a 5-point scale, from strongly disagree (1) to strongly agree (5). Twelve students in the course completed the pre- and post-survey in spring 2020, and 10 students completed both surveys in spring 2021. The ratings in Table 1 indicate median student responses to the various prompts from each semester. Because the experience of the course was different across the two semesters, we did not aggregate students' responses from spring 2020 and spring 2021.

Overall, students in this course felt positively about the utility of math and science, their capabilities related to engineering and problem-solving, and their abilities to work with peers, even at the beginning of the semester. In both semesters, students began the course with generally strong feelings about their abilities with building and fixing things, the utility of design to their future work, and the utility of integrated math and science for future invention. Students also came into the course confident in their abilities to work with peers, include others' perspectives, and make and adapt learning goals and plans. Additionally, students' participation in the course correlated with improved perceptions of the utility of integrated content knowledge and of their own abilities to produce high-quality work.

Even though students in both semesters began the course with positive perceptions, there were some notable differences in how students' perceptions changed in spring 2020 compared with spring 2021. There were seven statements—related to students' capabilities in engineering, collaboration, and independent problem-solving—toward which students felt less strongly at the end of spring 2020 compared with the beginning of spring 2020. For example, at the

Table 1. Students' perceptions of engineering and 21st-century learning in spring 2020 and spring 2021.

	2020 pre	2020 post	2021 pre	2021 post
Engineering and technology prompts				
I am good at building and fixing things.	4	3	4	4
Designing products or structures will be important for my future work.	3.5	3	4	4.5
Knowing how to use math and science together will allow me to invent useful things.	4	5	4	4.5
I believe I can be successful in a career in engineering.	3	3	4	5
21st-century learning prompts				
I am confident I can produce high-quality work.	4	5	4	4.5
I am confident I can respect the differences of my peers.	5	5	5	5
I am confident I can help my peers.	4.5	4	4	4
I am confident I can include others' perspectives when making decisions.	5	4.5	4	5
I am confident I can make changes when things do not go as planned.	4.5	4	4	4
I am confident I can set my own learning goals.	4.5	4	4	4.5
When I have many assignments, I can choose which ones need to be done first.	5	4.5	4	4
I am confident I can work well with students from different backgrounds.	5	5	4.5	5

Note. Students responded to each prompt on a scale from strongly disagree (1) to strongly agree (5). We present median responses. Twelve students responded to the pre- and post-survey in spring 2020, and 10 students responded in spring 2021.

beginning of spring 2020 the median response to the statement "I am good at building and fixing things" was "agree," but by the end of spring 2020 the median response was neutral. With respect to 21st-century learning activities, students in spring 2020 became slightly less confident in their abilities to help their peers, include others' perspectives, make changes when things do not go as planned, set their own learning goals, and prioritize their work on assignments. These decreases in spring 2020 are contrasted with students' experiences in the course in spring 2021, when they remained as confident or became more confident in the same areas.

There are multiple explanations for the differences in how students perceived their own capabilities throughout spring 2020 and spring 2021. We had a small number of survey respondents in each semester, so changes by a small number of students could impact median responses. Additionally, the circumstances of spring 2020 required changes to the structure of the course that happened with little warning, and these changes necessarily removed students' opportunities to work directly with the robots. When students' only means of collaboration required direct and constant supervision by course instructors, students became less confident in their abilities to work independently and with peers. In spring 2021, when students took turns maneuvering the robot and worked more independently of the course instructors, they developed more positive perceptions of their abilities to solve problems with their peers. Higher education continues to grapple with questions about how to make learning experiences meaningful, safe, and fair for all students. It is important to recognize the instructional design choices—for example, maintaining space on campus where students can access physical materials—that can support students in developing the skills necessary to solve transdisciplinary problems.

Conclusion

Transdisciplinary teaching and learning is a substantial undertaking, requiring faculty expertise as well as physical resources, space, and time. It is also a necessary undertaking for students to develop the knowledge and skills to solve the most important problems they will encounter. Educational robots have been useful in our context to bridge animal sensory biology with robotics engineering, and such connections could be made in areas beyond sensory biology as well. While educational robots have often been used to introduce students to the engineering design process more broadly, we have found that students can learn specific content while also developing engineering practices.

Some of the challenges associated with demands of transdisciplinary learning can be met through the adoption of hybrid, flexible collaboration models. Introducing students to the use of remote desktop software can make it easier for students with different schedules to work together. Establishing clear expectations about students' division of labor with respect to robotics hardware (e.g., who needs to be in the room with the robot, and when) can provide necessary structure for students to develop equitable work practices. These types of support create the conditions for students to work both independently and in collaboration with peers, creating an authentic context for students to take on transdisciplinary tasks.

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References

Astley, H. C., Rieser, J. M., Kaba, A., Paez, V. M., Tomkinson, I., Mendelson, J. R., & Goldman, D. I. (2020). Side-impact collision: Mechanics of obstacle negotiation in sidewinding snakes. *Bioinspiration and Biomimetics*, *15*(6), Article 065006. https://doi.org/10.1088/1748-3190/abb415

Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education*, *39*(3), 229–243. https://doi.org/10.1080/15391523.2007.10782481

Blanchard, S., Freiman, V., & Lirrete-Pitre, N. (2010). Strategies used by elementary schoolchildren solving robotics-based complex tasks: Innovative potential of technology. *Procedia Social and Behavior Sciences*, *2*(2), 2851–2857. https://doi.org/10.1016/j.sbspro.2010.03.427

Gibson, J. P., & Shelton, K. (2021). Introductory biology students' opinions about the pivot to crisis distance education in response to the COVID-19 pandemic. *Journal of College Science Teaching*, *51*(1), 12–18. https://doi.org/10.1080/0047231X.2021.12290537

Gravish, N., & Lauder, G. V. (2018). Robotics-inspired biology. *Journal of Experimental Biology*, *221*(7), 1–8. https://doi.org/10.1242/jeb.138438

Kaya, E., Newley, A., Deniz, H., Yesilyurt, E., & Newley, P. (2017). Introducing engineering design to a science teaching methods course through educational robotics and exploring changes in views of preservice elementary teachers. *Journal of College Science Teaching*, *47*(2), 66–75. https://doi.org/10.2505/4/jcst17_047_02_66

Manoonpong, P., & Tetzlaff, C. (2018). Neural computation in embodied closed-loop systems for the generation of complex behavior: From biology to technology. *Frontiers in Neurorobotics*, *12*, Article 53. https://doi.org/10.3389/fnbot.2018.00053

Martinez Ortiz, A., Bos, B., & Smith, S. (2015). The power of educational robots as an integrated STEM learning experience in teacher preparation programs. *Journal of College Science Teaching*, *44*(5), 42–47. https://www.jstor.org/stable/43631847 https://doi.org/10.2505/4/jcst15_044_05_42

National Research Council. (2012). *Education for life and work: Developing transferable skills in the 21st century*. National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.

Ohio Department of Education Department of Higher Education. (2020). *College credit plus: Annual report 2019–2020*. Ohio Department of Education. https://highered.ohio.gov/static/files/uploads/CCP/CCP-2020-Annual-Report_FINAL.pdf

Radloff, J. D., Guzey, S., Eighinger, D., & Capobianco, B. M. (2019). Integrating engineering design in undergraduate biology using a life science design task. *Journal of College Science Teaching*, *49*(2), 45–52. https://www.jstor.org/stable/26901367 https://doi.org/10.2505/4/jcst19_049_02_45

Shöne, H. (1984). *Spatial orientation: The spatial control of behavior in animals and man*. Princeton University Press.

Turner, K. L., Jr., & Hoffman, A. R. (2018). Integration, authenticity, and relevancy in college through engineering. *Journal of College Science Teaching*, *47*(3), 31–35. https://doi.org/10.2505/4/jcst18_047_03_31

Vanderelst, D., Steckel, J., Boen, A., Peremans, H., & Holderied, M. W. (2016). Place recognition using batlike sonar. *eLife*, *5*, Article 14188. https://doi.org/10.7554/eLife.14188

Vasquez, J. A. (2015). STEM: Beyond the acronym. *Educational Leadership*, *72*(4), 10–15.

Wiener, N. (1961). *Cybernetics: Or control and communication in the animal and the machine* (2nd ed.). MIT Press.