May/June 2019

Vol. 48, No. 5

Journal of College Science Teaching

- Modifying traditional labs to target scientific reasoning
- Exploring student perception toward online homework
- Integrating engineering into elementary science teaching

75th ANNIVERSARY NSTA National Science Teachers Association

Journal of College Science Teaching

...a Peer-Reviewed Journal Published by the National Science Teachers Association
Vol. 48, No. 5

Cover image: *Close-up of head of white thistle flower. Image by Hipgnosis for Shutterstock.*

FEATURES

RESEARCH AND TEACHING

ALSO IN THIS ISSUE

Journal of College Science Teaching
...a Refereed Journal Published by the
National Science Teachers Association

Editor .... *David Wojnowski*
dwojnowski@gsu.edu

Editor Emeritus .... *Lester G. Paldy*
lester.paldy@stonybrook.edu

Managing Editor .... *Caroline Barnes*
cbarnes@nsta.org

Assistant Executive Director of Journals
Kenneth L. Roberts
kroberts@nsta.org

Art Director .... *Will Thomas*
Senior Graphic Designer .... *Joseph Butera*
Graphic Designer .... *Hima Bichali*

Printing/Production Manager ..... *Catherine Lorrain*
Electronic Prepress Technician .... *Jack Parker*

Executive Director .... *David L. Evans*

Advertising .... *Jason Sheldrake*
Director
jsheldrake@nsta.org; 703-312-9273

The Journal of College Science Teaching [ISSN 0047-231x (print) 1943-4898 (online)] is published six times a year (Sept./Oct., Nov./Dec., Jan./Feb., March/April, May/June, July/Aug.) by the National Science Teachers Association, 1840 Wilson Blvd., Arlington, VA 22201-3000. Individual membership dues are $79 ($35 for publication, $44 for membership). Memberships outside the United States (except territories), add $15 per year for postage. Single copy price for nonmembers, $10. Periodicals postage paid at Arlington, VA, and additional mailing offices. Publications Mail Agreement no. 41506028. Return undeliverable Canadian addresses to: P.O. Box 503, RPO West Beaver Creek, Richmond Hill, ON L4B 4R6 Canada. **POSTMASTER:** Send address changes to the *Journal of College Science Teaching,* NSTA Member Services, 1840 Wilson Blvd., Arlington, VA 22201-3000.

NSTA National Science Teachers Association

Modifying Scientific Research Into Introductory Science Course Lessons Using a 5E Lesson Format: An Active Learning Approach

By Robert Idsardi, Daniel A. Hahn, Julie R. Bokor, and Julie A. Luft

Science faculty are being asked to create active learning experiences that engage students in core concepts and science practices. This article describes an approach to developing active learning lessons from authentic science research projects using the 5E lesson format. Included is a description of the 5Es and a template for creating a 5E lesson. A description of the authors' scientific research and the resulting 5E lesson for an introductory biology course are provided as an example of this approach. In the lesson described, students collected, analyzed, and interpreted data to construct explanations about the potential for evolution to occur in response to climate change. This approach supported students in learning core concepts and science practices and allowed the instructors to implement an active learning environment based on national science reforms. The results of this exploratory study and the rich descriptions of the lesson design should be used to raise awareness of one active-learning approach. Scientists can consider using this approach in their own teaching, and science education researchers can consider this approach in future comparative studies across various active-learning approaches.

Science, technology, engineering, and mathematics (STEM) play a vital role in society (President's Council of Advisors on Science and Technology, 2012). Instructors at all levels are crucial in having a scientifically literate society and meeting the increased demand for students pursuing STEM careers. Most STEM instructors implement the form of instruction they received as students (Ball, 1990; Sakshaug & Wohlhuter, 2010), which in undergraduate STEM courses often consists of extensive lecturing (Hurtado, Eagan, Pryor, Whang, & Tran, 2012; Stains et al., 2018).

Instead of extensive lecturing, undergraduate science courses should engage students in learning science through active learning (Freeman et al., 2014). Two documents have specific suggestions for how this instruction should be enacted: The *Next Generation of Science Standards* (NGSS Lead States, 2013) and *Vision and Change* (American Association for the Advancement of Science [AAAS], 2011).

Both documents challenge science faculty to create learning experiences that engage students in both core concepts and science practices. Learning core concepts should occur through participation in the practices of science. According to the *NGSS* (NGSS Lead States, 2013), these practices include asking questions, conducting experiments, testing hypotheses, analyzing data, constructing explanations, and using models.

This article describes our attempt to turn our scientific research, focused on evolution and climate change, into a learning experience aligned with *Vision and Change* (AAAS, 2011) and the *NGSS* (NGSS Lead States, 2013). Framing our instruction was the 5E lesson format (Bybee et al., 2006) that is widely used in K–12 science teaching and is emerging in undergraduate science instruction (Sickel, Witzig, Vanmali, & Abell, 2013). This article will enable other scientists to consider one way to implement active learning through the 5E model and will also provide the foundation for future comparative studies of this model of instruction to other forms of active learning through rich descriptions of the lesson.

The pedagogy

It is well documented that active learning increases student performance when compared with traditional lecturing in undergraduate STEM courses (Freeman et al., 2014). Active learning was defined by Freeman et al. (2014) as "engaging students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (pp. 8413–8414).

Active learning can vary widely in intensity and implementation. Erol, Idsardi, Luft, Myers, and Lemons (2015) described a range of active learning from entry-level techniques (e.g., clickers) to more advanced techniques (e.g., flipped classrooms and case studies).

Freeman et al. (2014) argued that studies comparing various kinds of active learning to traditional lecturing represented the “first-generation” of research in this field (p. 8413). They also argued that it is time for “second-generation” research that moves beyond comparisons to traditional lecturing (p. 8413). Instead, studies should evaluate what aspects of active learning are most effective at promoting student learning. For example, Jensen, Kummer, and Godoy (2015) compared an active flipped classroom to an active nonflipped classroom. The authors used the 5E model to design both courses. Results indicated equivalent student learning outcomes in both courses.

The purpose of this article is to describe how we used the 5E model to modify our scientific research into a classroom investigation. We did not compare this approach to traditional lecturing, as results in the literature are overwhelming that active learning better supports student performance than extensive lecturing (Freeman et al., 2014). A quasi-experimental design comparing the 5E approach described here to another active-learning approach was beyond the scope of this study. The results of this exploratory study and the rich descriptions of the lesson design should be used to raise awareness of one active-learning approach. Instructors can consider using this approach in their own teaching, and science education researchers can consider this approach in future second-generation active-learning studies.

The science

Understanding the impact of climate change on organisms is important and constitutes a portion of our scientific research. Beyond increases in global mean temperatures, climate change is expected to result in more frequent extreme weather events (Easterling et al., 2000; Vasseur et al., 2014; Williams, Henry, & Sinclair, 2015). These events include snap freezes, in which local temperatures rapidly shift from warm to cold. Snap freezes are well-known for their impact on crops, but they also have major effects on ectothermic animals, such as insects, lizards, and turtles. Insect populations are critical in many ecosystems, and their fluctuations during stressful temperatures will affect these ecosystems (Scheffers et al., 2016).

Our research focuses on chill coma recovery time, a genetically controlled trait relevant to snap freezes, in the fly *Drosophila melanogaster* (MacKay et al., 2012; Williams et al., 2014; Williams et al., 2016). An effect of cold temperatures on *Drosophila*, and many ectotherms, is an induced state of narcosis known as chill coma (Gibert, Moreteau, Pétavy, Karan, & David, 2001). Chill coma recovery time is the time it takes an organism to return from an inactive state to an active state. This is often measured by recording when the insect regains the ability to stand on all six legs.

FIGURE 1

Template for the development of an inquiry-based investigation in a life science course using the 5E model.

Summary of Investigation (Focus on Phenomena)

NGSS	***Vision and Change***
Disciplinary Core Ideas: Science and Engineering Practices: Crosscutting Concepts:	Core Concept: Core Competency:

ENGAGE	EXPLORE	EXPLAIN	ELABORATE	EVALUATE
(Describe activity that engages students and elicits prior knowledge)	(Describe activity within which current concepts, processes, and skills are identified and conceptual change is facilitated through generating new ideas, exploring questions, and designing and conducting an investigation)	(Describe how a concept, process, or skill is directly introduced by the instructor or other resources to guide learners toward a deeper understanding)	(Describe how students will apply their understanding of the concept through additional activities)	(Describe the evaluation of student progress toward achieving the learning outcomes)

Reflection About the Investigation

(After the lesson, reflect on the enactment of the lesson and record evidence regarding student performance)

The organisms used in our research were a series of lines from the *Drosophila* Genetic Reference Panel (DGRP; Mackay et al., 2012). Almost 200 genetically distinct lines were created by inbreeding females captured from a wild population in Raleigh, North Carolina. Inbreeding removes genetic variation within each line so each line represents a single genotype. Together, the lines represent a sample of the standing genetic and phenotypic variation in the wild population. By investigating this sample, we can characterize the genetic and physiological mechanisms underlying climate-relevant traits (MacKay et al., 2012; Williams et al., 2014; Williams et al., 2016).

A secondary science curriculum was initially designed based on this research (Broo & Mahoney, 2017; Broo, Mahoney, Bokor, & Hahn, 2018). This research was further modified into a 5E lesson for an undergraduate biology course for preservice teachers. In the lesson, students recorded and analyzed chill coma recovery times of multiple lines of genetically distinct *Drosophila* flies. Students explored how some lines handle snap freezes better than others and predicted how this population could respond via natural selection to climate change.

Lesson design

The lesson was designed using the template found in Figure 1. The 5E lesson plan template was created to support undergraduate STEM instructors' implementation of active learning. The first box in the template provides space to describe the concept(s) targeted in the lesson. In this investigation the concept was the potential evolutionary impact of climate change on ectotherms.

The next two boxes provide space for instructors to list the learning objectives of the lesson. This lesson aligned with the *NGSS* performance expectations in evolution and ecology, and engaged students in the *NGSS* science practices of carrying out investigations, analyzing and interpreting data, and constructing explanations. From *Vision and Change* (AAAS, 2011), the lesson spanned two core concepts: evolution and systems. Within evolution, the lesson emphasized genetic variation and natural selection. Within systems, the lesson emphasized the dynamic interactions of components in a system.

The *NGSS* can be utilized by faculty across science disciplines. The *NGSS* include interdisciplinary science and engineering practices and crosscutting concepts, as well as disciplinary core ideas in physical science, life science, and Earth and space science. *Vision and Change* (AAAS, 2011) focuses on core competencies in biology. Faculty in other disciplines can substitute the box for *Vision and Change* with core competencies in their discipline. For example, the American Chemical Society provides conceptual topics and practical tools students should know.

The entire lesson was placed in a 5E format (Table 1). Throughout the 5E lesson students interacted with each other and the instructor. These interactions allowed students to exchange their unique perspectives, promoted collaborative learning, and served as a formative assessment for instructors to evaluate students' understandings and guide instruction (e.g., McDonald, 2016). The third row of boxes in Figure 1 was designed for instructors to describe the activities planned to engage students in each of the 5Es.

The instructor evaluated the lesson by interacting with students throughout the lesson. Both during

TABLE 1

The BSCS 5Es instructional model (Bybee, 2014).

Engagement	The teacher or a curriculum task helps students become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions, and design and conduct an investigation.
Explanation	The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. In this phase teachers directly introduce a concept, process, or skill. An explanation from the teacher or other resources may guide learners toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept and abilities by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and allows teachers to evaluate student progress toward achieving the learning outcomes.

and after the lesson, the instructor reflected on the lesson and recorded student performance. The last box in the template in Figure 1 was designed for instructors to record these reflections. For instance, after class the instructor could note areas in which additional instruction might be useful, or instructors could identify concepts that students grasped easily.

Enacting the lesson

Next, we describe the enactment of our 5E lesson. First, we describe the context of the course in which the lesson was enacted. Then, we describe the enactment of each of the 5Es.

The students and the class

The lesson was implemented in an undergraduate general biology class for preservice teachers. The class met once a week for 3 hours in a standard classroom without laboratory space. Lessons in the class had minimal lecturing. Instead, students regularly worked in pairs or small groups and presented their emerging conclusions to the class for further discussion.

Eight of the 11 students in the course were pursuing a bachelor of science in education (BSEd), and three students were completing a master of education in science education (MEd) degree. Students' experiences with postsecondary science content courses were similar to those of many nonscience majors and included minimal science courses beyond general education requirements. Ten of the students were female, and one was male.

The 5E lesson

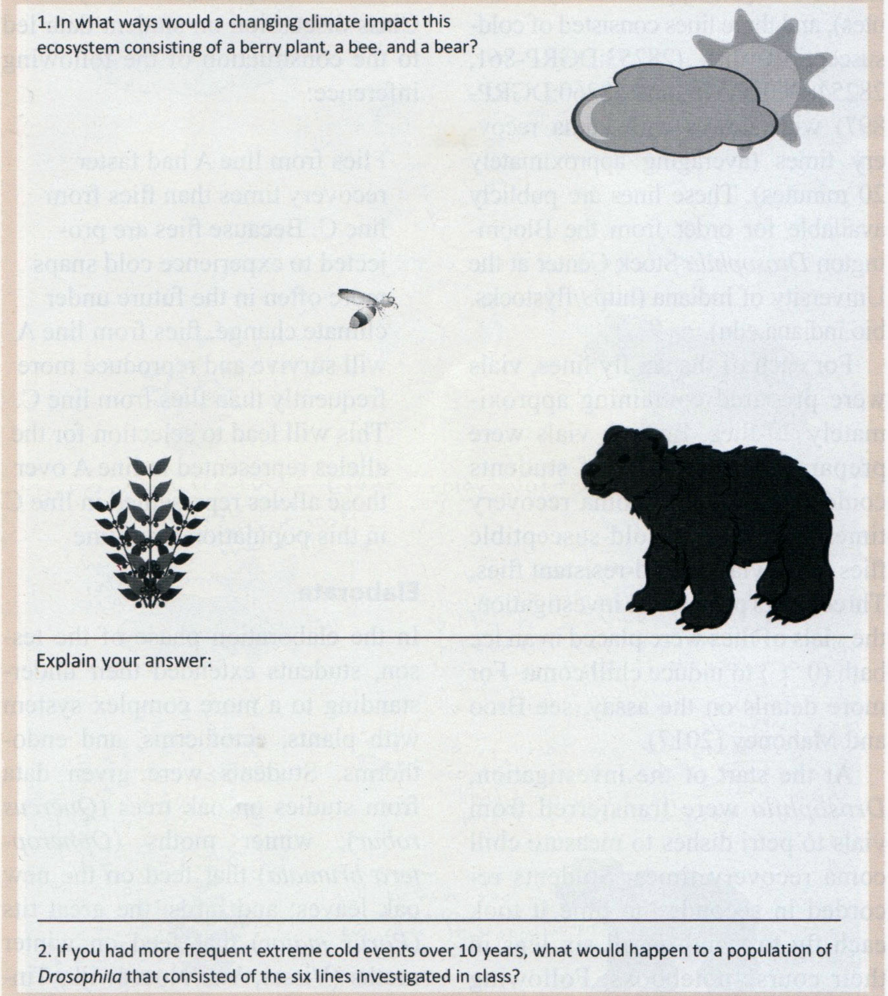
Engage

Prior to the investigation, students completed a concept sketch of how changes in climate affect various organisms to elicit students' prior knowledge (see Problem 1 in Figure 2). The concept sketch process can be used as a formative assessment to evaluate the content knowledge of undergraduates (Johnson & Reynolds, 2005). The sketch included a plant, an ectotherm, and a mammal from a single food web. This formative assessment elicited students' preconceptions of how organisms are connected in ecosystems and how environmental change (e.g., climate change) can impact populations within ecosystems.

The instructor then introduced students to the DGRP lines and the concept of snap freezes through the "think-pair-share" approach. Discussions centered on a series of questions that built on the formative assessment in Figure 2. Questions included: "How does temperature affect organisms?" "What impacts would a changing climate have on organisms?" and "What are ways in which organisms can respond to climate change?" Students first individually wrote their ideas in their lab notebooks, then discussed their answers in small groups, and finally shared their answers in a whole-class discussion. The instructor used follow-up questions to push students' thinking and had several slides prepared to introduce students to content with which they were un-

FIGURE 2

Assessment of student understanding of natural selection in response to climate change. Students first completed Problem 1 in the engage and evaluate portion of the lesson. A week following the lesson, students took an exam that included both Problems 1 and 2.



1. In what ways would a changing climate impact this ecosystem consisting of a berry plant, a bee, and a bear?

Explain your answer:

2. If you had more frequent extreme cold events over 10 years, what would happen to a population of *Drosophila* that consisted of the six lines investigated in class?

familiar, such as snap freezes.

In this study, students' initial ideas about climate change were limited to increases in mean temperatures. Students' initial ideas about the impacts of climate change on organisms were limited to effects on individual organisms. Students did not consider how impacts on one organism would affect others until prompted with follow-up questions.

Explore

Students were then introduced to the chill coma assay (Denlinger & Lee, 2010). In preparing for the investigation, six genetically distinct lines of *Drosophila* from the DGRP were obtained from Daniel A. Hahn's research group. Three lines consisted of cold-resistant flies (25186:DGRP-360, 25198:DGRP-555, and 28178:DGRP-356) with faster chill coma recovery times (averaging approximately 8 minutes), and three lines consisted of cold-susceptible flies (28253:DGRP-861, 28254:DGRP-879, and 28260:DGRP-897) with slower chill coma recovery times (averaging approximately 20 minutes). These lines are publicly available for order from the Bloomington *Drosophila* Stock Center at the University of Indiana (http://flystocks.bio.indiana.edu).

For each of the six fly lines, vials were prepared containing approximately 20 flies. Enough vials were prepared so each pair of students could measure chill coma recovery times of a vial of cold-susceptible flies and a vial of cold-resistant flies. Three hours prior to the investigation, the vials of flies were placed in an ice bath (0 °C) to induce chill coma. For more details on the assay, see Broo and Mahoney (2017).

At the start of the investigation, *Drosophila* were transferred from vials to petri dishes to measure chill coma recovery times. Students recorded in seconds the time it took each fly to stand on all six legs in their course notebooks. Following data collection, each student pair entered their data into a single Excel spreadsheet for the whole class to use during data analysis. This resulted in a pooled data set of approximately 40 flies in each of the six fly lines. The mean and standard deviation were calculated for each line.

Explain

Students used the class data to make inferences about variation in chill coma recovery time across fly lines. In a follow-up class discussion, students were asked about the potential for this population of flies to adapt to climate change through selection for faster chill coma recovery.

One ideal conclusion reached by the students was that climate change (e.g., increased frequency of snap freezes) could lead to directional selection in genetically diverse populations. Selection would favor advantageous traits (e.g., fast recovery time). Class discussion on student data led to the construction of the following inference:

> Flies from line A had faster recovery times than flies from line C. Because flies are projected to experience cold snaps more often in the future under climate change, flies from line A will survive and reproduce more frequently than flies from line C. This will lead to selection for the alleles represented in line A over those alleles represented in line C in this population over time.

Elaborate

In the elaboration phase of the lesson, students extended their understanding to a more complex system with plants, ectotherms, and endotherms. Students were given data from studies on oak trees (*Quercus robur*); winter moths (*Operophtera brumata*) that feed on the new oak leaves; and birds, the great tits (*Parus major*) that feed on winter moths (Visser, Van Noordwijk, Tinbergen, & Lessells, 1998). Students observed increasing differences between the date great tits laid their eggs and the date winter moth caterpillars peaked over time. This challenged students to apply the lessons learned from the investigation to a new and more complex context. Students considered how organisms can respond to climate change at different rates and that natural selection can act on some populations more rapidly than others. For example, one student stated, "Changes in one organism can affect others. If insects died from an extreme cold snap, they would not be able to pollinate plants leading to less food for herbivores and omnivores."

Evaluate

A week following the investigation, students were asked to again sketch or describe ways in which climate change impacts various organisms in ecosystems (Figure 2, Problem 1), and to explain their answers. In addition, students were asked a more direct question assessing their understanding of the chill coma investigation (Figure 2, Problem 2). Students were asked to predict what would happen in the population of *Drosophila* that was investigated if extreme cold events occurred frequently over a 10-year period. This question assessed the degree to which students understood that climate change could result in directional selection over time for advantageous genetically controlled traits and selection against unfavorable genetically controlled traits. Exemplary responses included:

> Organisms with traits that confer an advantage in response to environmental pressures survive and reproduce more frequently than those with less favorable traits.

> It appears that it would be advantageous to be a fly from a strain that recovers most rapidly. Lines A and B will survive more than

graduate level to engage students in science content and science practices.

Reform-based instruction is especially important for undergraduate science courses that enroll preservice teachers. Beyond promoting the conceptual development of science content knowledge for all undergraduate students, this approach models effective instruction preservice teachers can later implement in their own teaching. It is important to engage preservice teachers in science practices and active learning in science content courses because teachers will generally teach in the ways they were taught (Ball, 1990; Sakshaug & Wohlhuter, 2010). Ultimately, active learning benefits future teachers and their students by demonstrating how to learn science through engagement in science practices. ■

Acknowledgments

This work was funded by National Science Foundation grants IOS-1257298 and DEB-1639005 to Dan Hahn, and the University of Georgia Athletic Association Professorship in Mathematics and Science Education to Julie Luft. The findings, conclusions, and opinions herein represent the views of the authors and do not necessarily represent the views of personnel affiliated with the National Science Foundation or the University of Georgia. We also appreciate the contributions of Paula Lemons, Peggy Brickman, and Colleen Kuusinen, who reviewed and provided feedback on the manuscript.

References

American Association for the Advancement of Science. (2011). *Vision and change in undergraduate biology education*. Washington, DC: Author. Retrieved from http://visionandchange.org/files/2011/03/Revised-Vision-and-Change-Final-Report.pdf

Ball, D. L. (1990). The mathematical understandings that prospective teachers bring to teacher education. *Elementary school Journal, 90,* 449–466.

Broo, J., & Mahoney, J. (2017). *Drowsy Drosophila: Rapid evolution in the face of climate change.* Gainesville, FL: University of Florida, Center for Precollegiate Education and Training. Retrieved from https://www.cpet.ufl.edu/wp-content/uploads/2014/12/Intro_DrowsyDrosophila2017.pdf

Broo, J., Mahoney, J., Bokor, J., & Hahn, D. A. (2018). *Drowsy Drosophila: Rapid evolution in the face of climate change.* American Biology Teacher, 80, 272–277.

Bybee, R. W. (2014). The BSCS 5E instructional model: Personal reflections and contemporary implications. *Science and Children, 51*(8), 10–13.

Bybee, R. W., Taylor, J. A., Gardner, A., Vanscotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness and applications*. Colorado Springs, CO: BSCS.

Denlinger, D. L., & Lee, R. E., Jr. (Eds.). (2010). *Low temperature biology of insects.* New York, NY: Cambridge University Press.

Easterling, D. R., Meehl, G. A., Parmesan, C., Changnon, S. A., Karl, T. R., & Mearns, L. O. (2000). Climate extremes: Observations, modeling, and impacts. *Science, 289*(5487), 2068–2074.

Erol, M., Idsardi, R., Luft, J. A., Myers, D., & Lemons, P. P. (2015). *Creating active learning environments in undergraduate STEM courses.* Athens, GA: University of Georgia Foundation.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, USA, 111,* 8410–8415.

Gibert, P., Moreteau, B., Pétavy, G., Karan, D., & David, J. R. (2001). Chill-coma tolerance, a major climatic adaptation among Drosophila species. *Evolution, 55,* 1063–1068.

Hurtado, S., Eagan, K., Pryor, J. H., Whang, H., & Tran, S. (2012). *Undergraduate teaching faculty: The 2010–2011 HERI Faculty Survey.* University of California, Los Angeles, CA: Higher Education Research Institute.

Jensen, J. L., Kummer, T. A., & Godoy, P. D. d. M. (2015). Improvements from a flipped classroom may simply be the fruits of active learning. *CBE—Life Sciences Education, 14*(1), ar5.

Johnson, J. K., & Reynolds, S. J. (2005). Concept sketches—using student- and instructor-generated, annotated sketches for learning, teaching, and assessment in geology courses. Journal of Geoscience Education, 53(1), 85–95.

MacKay, T. F., Richards, S., Stone, E. A., Barbadilla, A., Ayroles, J. F., Zhu, D., . . . Richardson, M. F. (2012). The Drosophila melanogaster genetic reference panel. *Nature, 482*(7384), 173–178.

McDonald, J. T. (2016). What does formative assessment look like in the college science classroom? *Journal of College Science Teaching, 45*(6), 8–9.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. Retrieved from www.nextgenscience.org/next-generation-science-standards

President's Council of Advisors on Science and Technology. (2012). *Report to the President: Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics.* Washington, DC: White House.

Sakshaug, L. E., & Wohlhuter, K. A. (2010). Journey toward teaching mathematics through problem solving. *School Science and Mathematics, 110*(8), 397–409.

Scheffers, B. R., De Meester, L., Bridge, T. C., Hoffmann, A.

A., Pandolfi, J. M., Corlett, R. T., . . . Pacifici, M. (2016). The broad footprint of climate change from genes to biomes to people. *Science, 354*(6313), aaf7671.

Sickel, A. J., Witzig, S. B., Vanmali, B. H., & Abell, S. K. (2013). The nature of discourse throughout 5E lessons in a large enrolment college biology course. *Research in Science Education, 43,* 637–665.

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., . . . Levis-Fitzgerald, M. (2018). Anatomy of STEM teaching in North American universities. *Science, 359*(6383), 1468–1470.

Williams, C. M., Watanabe, M., Guarracino, M. R., Ferraro, M. B., Edison, A. S., Morgan, T. J., . . . Hahn, D. A. (2014). Cold adaptation shapes the robustness of metabolic networks in Drosophila melanogaster. *Evolution, 68,* 3505–3523.

Williams, C. M., Henry, H. A. L., & Sinclair, B. J (2015). Cold truths: How winter drives responses of terrestrial organisms to climate change. *Biological Reviews, 90,* 214–235.

Williams, C. M., Szjner-Sigal, A., Morgan, T. J., Edison, A. S., Allison, D. B., & Hahn, D. A. (2016). Adaptation to low temperature exposure increases metabolic rates independently of growth rates. *Integrative and Comparative Biology, 56,* 62–72.

Vasseur, D. A., DeLong, J. P., Gilbert, B., Greig, H. S., Harley, D. G., McCann, K. S., . . . O'Connor, M. I. (2014). Increased temperature variation poses a greater risk to species than climate warming. *Proceedings of the Royal Society B: Biological Sciences, 281,* 20132612.

Visser, M. E., Van Noordwijk, A. J., Tinbergen, J. M., & Lessells, C. M. (1998). Warmer springs lead to mistimed reproduction in great tits (Parus major). *Proceedings of the Royal Society of London B: Biological Sciences, 265*(1408), 1867–1870.

***Robert Idsardi** (ridsardi@ewu.edu) is an assistant professor of biology education in the Department of Biology at Eastern Washington University in Cheney, Washington. **Daniel A. Hahn** is a professor of evolutionary physiology in the Entomology and Nematology Department at the University of Florida in Gainesville. **Julie R. Bokor** is the associate director of the Center for Precollegiate Education and Training at the University of Florida in Gainesville. **Julie A. Luft** is the Athletic Association Professor of Mathematics and Science Education in the Department of Mathematics and Science Education at the University of Georgia in Athens.*

Exploring Student Perception Toward Online Homework and Comparison With Paper Homework in an Introductory Probability Course

By Philip Matchett Wood and Vijesh Bhute

Online software systems are extensively used to give students practice on course content, especially in mathematics and physics courses. They offer instant feedback, and several of these systems are open source or very economical compared with hiring graders for traditional paper-and-pencil–based homework (PPH). In this article, the authors evaluate WeBWorK (WW), an online software tool, in an introductory course on probability over two semesters. WW is compared with PPH by measuring student perception, average time spent on a problem, collaborative work outside of classroom, resilience, self-efficacy, and exam performance. The authors find that except for working in groups on homework, students perform similarly on all the aforementioned aspects in both PPH and WW. The authors also suggest potential strategies to improve student understanding and learning while using WW and recommend the use of WW in mathematics-oriented courses.

Homework assignments are a critical component of college education, especially in mathematics-oriented courses. Homework assignments can serve multiple instructional purposes, which are reviewed in detail by Bas, Senturk, and Mehmet Ciherci 2017), including offering students opportunities to review concepts taught in the classroom (Bas et al., 2017; Cooper, 2007). Conventional homework, also known as paper-and-pencil–based homework (PPH), involves students working on problems outside the classroom and returning their solutions after a fixed duration of time. In PPH, students are unable to check whether their answers are correct until they submit their work and receive the solutions from the instructor. Also, in PPH, the grading of the homework assignments is usually done by paid graders, which can introduce heterogeneity and subjectivity. Online homework can overcome these challenges by providing instantaneous feedback (Mavrikis & Maciocia, 2003) and eliminating the need for paid graders. WeBWorK (WW), an open-source online homework system, has emerged as a viable alternative to the traditional PPH assignments in several mathematics-oriented subjects (Roth, Ivanchenko, & Record 2008), including calculus (Goehle, 2013), algebra (Hauk & Segalla, 2013), probability and statistics (Lucas, 2012; Segalla & Hauk, 2010), and economics (Mitchell & Mitchell, 2017). WeBWorK (WW) successfully evaluates equivalent mathematical expressions as correct; however, WW does not generally differentiate between answers that are slightly wrong versus completely wrong. Problems in WW typically have some randomized parameters to discourage students from inputting correct answers from another student. Students' perception toward WW and the effect of WW-based assignments on their performance on exams have been investigated in several studies (Goehle, 2013; Hauk & Segalla, 2013; Lucas, 2012; Mitchell & Mitchell, 2017; Roth et al., 2008; Segalla & Hauk, 2010). The effect that using WW has on student performance is ambiguous—although some studies observed a minor improvement in student performance, others failed to see any statistically significant improvement.

Student learning is a multifaceted process, and several factors can significantly affect learning. Despite extensive research on general perception and student performance, the influence of WW on a number of learning factors is not well studied.

Improving Preservice Elementary Teachers' Engineering Teaching Efficacy Beliefs With 3D Design and Printing

By Erdogan Kaya, Anna Newley, Ezgi Yesilyurt, and Hasan Deniz

The Framework for K–12 Science Education and the Next Generation Science Standards (NGSS) underscore the importance of including engineering design process (EDP) within the science curriculum. The Framework and the NGSS raised engineering design to the level of scientific inquiry in an attempt to prepare a STEM-literate workforce for the 21st century. Science teachers and elementary teachers do not have the required pedagogical content knowledge and self-efficacy to integrate engineering design in their own teaching. We believe that preservice elementary teachers should be taught how to integrate the EDP into their teaching and think that introducing 3D printing into preservice elementary science teaching methods courses can be an effective method for integrating engineering into elementary science teaching. In this study, our purpose is twofold: (a) provide a detailed explanation of how 3D printing is integrated into the EDP within the context of an elementary science teaching methods course and (b) investigate the changes in preservice elementary teachers' engineering teaching efficacy beliefs as a result of their participation in an engineering design challenge that requires 3D printing. Our results revealed an increase in PST engineering teaching efficacy beliefs.

Achieve, Inc., with the assistance of the National Research Council (NRC) and the National Science Teachers Association, released K–12 engineering standards as part of the *Next Generation Science Standards* (NGSS Lead States, 2013). With the release of the *NGSS*, elementary science teachers are now required to integrate engineering into their teaching. The *NGSS* challenge teachers to guide elementary students' inherent ability to design and build toward meaningful problem solving with the engineering design process (EDP; NGSS Lead States, 2013).

Taking Science to School (NRC, 2007) underlined that elementary students come to school with prior experience and understanding of science and engineering. Although lacking the core knowledge and skills, elementary students have the capacity to learn engineering with necessary scaffolding. Dewey underscored the importance of personal interest and prior conceptions in students' career choices (Dewey, 1913). Meaningful and relevant topics ignite students' natural interest (Cook, Bush, & Cox, 2015). Thus, a well-designed engineering curriculum may spark student interest in an engineering field.

Elementary students are natural designers and builders. They construct toys for playing and use novel apparatus and design structures in their games (Cunningham & Hester, 2007; NRC, 2012; NGSS Lead States, 2013). Their creativity inspires unique engineering designs with limited materials. The *NGSS* challenge teachers to guide this natural talent toward meaningful problem solving with the EDP. In elementary classrooms, the EDP can be introduced as: (a) defining the problem, (b) designing solutions, and (c) optimizing design solutions (NGSS Lead States, 2013). In upper elementary grades, teachers can introduce predetermined criteria and constraints for an engineering design solution as part of an engineering design challenge to make the engineering design experience more realistic (NGSS Lead States, 2013; NRC, 2012). Introducing the EDP in early elementary grades may spark all students' interest in engineering careers. However, there are two obstacles preventing elementary students from developing an interest in engineering. First, the instructional time devoted to engineering in elementary school curriculum is limited. Engineering subjects have been neglected or minimized for the sake of standardized tests such as English language arts and math (Bull, Knezek, & Gibson, 2009; Deniz, Yesilyurt, & Kaya, 2017). Second, even if elementary teachers are given more time to teach engineering, they may not be inclined to teach it because they lack confidence and appropriate pedagogical content knowledge (Deniz, Yesilyurt, & Kaya, 2017;