

Introducing ‘Making’ to Elementary and Secondary Preservice Science Teachers Across Two University Settings

by Shelly R. Rodriguez, The University of Texas, Austin; Steven S. Fletcher, St. Edwards University; & Jason R. Harron, The University of Texas, Austin

Abstract

‘Making’ describes a process of iterative fabrication that draws on a DIY mindset, is collaborative, and allows for student expression through the creation of meaningful products. While making and its associated practices have made their way into many K-12 settings, teacher preparation programs are still working to integrate making and maker activities into their courses. This paper describes an end-of-semester maker project designed to introduce preservice science teachers to making as an educational movement. The project was implemented in two different higher education contexts, a public university secondary STEM introduction to teaching course and a private university elementary science methods course. The purpose of this article is to share this work by articulating the fundamental elements of the project, describing how it was enacted in each of the two settings, reviewing insights gained, and discussing possibilities for future iterations. The project’s instructional strategies, materials, and insights will be useful for those interested in bringing making into science teacher preparation.

Keywords: constructionism; making; preservice; project-based; science education

Introduction

Over the past decade, there has been a surge of interest in how the field of education can benefit from the tools, processes, and practices of *making* (e.g., Clapp, Ross, Ryan, & Tishman, 2016; Fields, Kafai, Nakajima, Goode, & Margolis, 2018; Halverson & Sheridan, 2014; Stager & Martinez, 2013). Drawing from a “do it yourself” (DIY) mindset, classroom-based making can be defined as an iterative process of fabrication that allows students to express themselves through the creation of personally meaningful products that are publicly shared (Rodriguez, Harron, & DeGraff, 2018). Like traditional science and engineering practices, making involves the building of models, theories, and systems (NSTA, 2013). However, in contrast to these practices, making explicitly emphasizes the development of personal agency and student empowerment through creative, hands-on learning experiences that are both exciting and motivating (Clapp et al., 2016; Maker Education Initiative, n.d.). A shift towards maker-centered learning provides an opportunity to rethink how we prepare science educators with the aim of bringing more student-driven and personally meaningful experiences to their instructional practice.

Comparable to project-based learning (PBL) and other inquiry-based teaching practices, classroom making involves learning by doing. Maker-centered learning shares many elements found in *High Quality Project Based Learning* (HQPBL, 2018) which suggests that projects should include intellectual challenge and accomplishment, authenticity, collaboration, project management, the creation of a public product, and reflection. These elements overlap significantly with features of classroom-based making (Rodriguez, Harron, Fletcher, & Spock, 2018). However, maker-centered learning draws specifically on the theoretical underpinnings of constructionism (Papert, 1991), where learners gain knowledge as they actively design and build tangible digital or physical objects. Furthermore, maker-centered learning places emphasis on the originality and personal meaning of creations, the productive use of tools and materials in fabrication, the process of iterative design, and the development of a maker mindset that is growth-oriented and failure positive (Martin, 2015). Thus, in maker-centered learning, the skills of construction and design are acquired alongside the content.

There are several examples of the tools and materials associated with making being used as a way to help students explore the natural world (Bevan, 2017; Peppler, Halverson, & Kafai, 2016). For example, the use of copper tape, LEDs, and coin cell batteries have provided an avenue for science teachers to introduce circuits through the creation of interactive pop-up books and user-friendly paper circuit templates (Qi & Buechley, 2010, 2014). Sewable circuits, which use conductive thread, have been shown to improve student interest in science (Tofel-Grehl et al., 2017) and can be used in conjunction with embedded electronics, such as the Arduino-based Lilypad, to introduce computer science through the creation of e-textiles (Fields et al., 2018). However, not all making is digital. Making also includes traditional work such as welding, sewing, wood working, and other techniques that exist outside of the computational world.

The National Science Foundation (NSF) has acknowledged the potential of making to foster innovation, increase student retention, and broaden participation in science, technology, engineering, and mathematics (STEM) (National Science Foundation, 2017). However, more must be done to prepare future science educators to implement these practices in their classrooms. A national survey found that only half of undergraduate teacher preparation programs in the United States provided an opportunity to learn about maker-education and the associated technologies, and that only 17% had a makerspace available to their preservice teachers (Cohen, 2017). As such, many future educators are not exposed to formal training or professional development related to making. Since science teachers often uptake and implement the inquiry-based practices with which they have personal experience (Windschitl, 2003), a lack of exposure to maker-centered pedagogies may leave future educators unaware of the potential benefits of these innovations for their students.

This paper describes an end-of-semester project designed to introduce students to making as an educational movement. The project was implemented in two different settings. One was an introductory course offered as part of a secondary STEM teacher preparation

program at a large public research university. The other was a science methods course designed for preservice elementary teachers offered at a private university. The purpose of this article is to share our work by articulating the fundamental elements of the project, describing the project as enacted in these two settings, reviewing insights gained, and discussing possibilities for future iterations.

The Maker Project

The maker project described in this paper was introduced four years ago in a secondary STEM teacher preparation course for a number of reasons. The first was to expose novice teachers to the practice of using open-ended projects with high levels of personal agency to uncover student ideas. The second was to spark creativity in the preservice teachers and engage them in the act of authentic problem solving. The final reason was to provide an opportunity for preservice teachers to interact with up-to-date educational tools that they may encounter in schools. Two years later, an elementary science methods course housed in a private university adopted this activity for similar reasons, with the additional hope of increasing preservice teacher self-efficacy around science content and tool use – a noted deficiency in the literature (Menon & Sadler, 2016; Rice & Roychoudhury, 2003; Yoon, et al., 2006).

The following section outlines strategies used to implement the project in the two different science teacher preparation settings. The fundamental elements of the project in both settings include: a) an introduction to making; b) a station activity to expose students to new technologies and materials; c) an open-ended construction task; d) extended out of class time to create a personally meaningful artifact; e) the public presentation of work to classmates, instructors, and guests; and f) reflections for the classroom. Table 1 provides description of each setting and an overview of how the project features were enacted.

Table 1 (Click on image to enlarge)

Project Features in Each Context

	Introductory Secondary STEM Teaching Course	Elementary Science Methods
Program Context	Public, R1 University 1 credit hour course 1 st course in teacher prep sequence Designed for those interested in secondary STEM teaching including science, mathematics, engineering, and CS	Private, liberal arts university 3 credit hour course Last year of teacher prep sequence Designed for those interested in elementary teaching
Project feature: Introduction to making	-Make magazine video -Prompt during video "What is making?" -Small group & class discussion	Same
Project feature: Station activity	-Students break into groups -Stations: Scratch, Instructables, Makey Makey, and Circuit Playground -Student farther in the program and instructor serve as facilitators	-Student break into groups -Stations: Instructables, Makey Makey, paper circuits and bristlebots. -Instructor facilitates
Project feature: Open-ended construction task	a) Make an artifact demonstrating your growth as a teacher over the semester	a) Share a product that documents your exploration and demonstrates its possible usefulness in the classroom or b) Investigate some making and create a visual product that highlights what you learned along with a brief written summary of your research
Project feature: Extended out of class time for creation	-Two weeks to complete the project -Option to check out tools that were explored -Instructor and TA are available to help students outside of class	-Three weeks to complete the project -Instructor available to help students outside of class
Project feature: Presentation of work	-On the last class day students present their creation to peers, instructors, and guests Science Fair style	-During finals, presentations held at local children's museum
Project feature: Reflection	-Reflection on making, classroom application, and the overall project experience	-Reflection on project challenges and how making can be incorporated into the classroom.

Context Specific Implementation

Implementation in an introductory secondary STEM teacher preparation course

The introductory secondary STEM teacher preparation course is a 90-minute, one credit hour class in a large R1 university in central Texas. It meets once a week with approximately 25 students in each of five sections. The class is considered a recruitment course and is designed to give STEM majors the chance to try out teaching. In this class, students observe and teach a series of STEM lessons in local elementary schools. Those choosing to continue with the program will go on to teach in middle and high school settings and ultimately earn their teaching certification in a secondary STEM field. In the Fall of 2018, 53% of the students in the course were female and 47% male. 64% were underclassmen, 36% were either juniors, seniors, or post baccalaureate students, and 59% had either applied for or were receiving financial aid. 46% were science majors, 16% were math majors, 11% were computer science and engineering majors, 4% were degree holders, and the remaining students were assigned to other majors or undecided.

In class. The maker project in this course began with a project introduction day occurring approximately three weeks from the end of the semester. To start, students were introduced to the concept of making through a video created by *Make: magazine* and presented with a prompt, "What is making?", to think about as they watch the video (Maker Media, 2016). The video describes making as a DIY human endeavor that involves creating things that tell a personal story. After the video screening, students engaged in a Think-Pair-Share activity where they discussed the initial prompt in small groups and shared ideas in a whole class discussion, often describing making as personal, innovative, open-ended, and challenging (See Figure 1).

Figure 1 (Click on image to enlarge). Student ideas about making.



Next, the criteria for the final maker project was provided. The specific prompt for this project asked students to reflect on their teaching experience and to make an artifact that illustrated the story of their growth over the semester. Students were shown examples of what others had created in previous semesters. Some past projects featured traditional construction and craft materials such as woodworking and papier-mâché while others included digital tools such as 3D printing, block-based coding, and Arduinos. Students were also shown examples of maker projects as enacted in STEM classrooms such as activities that have K-12 pupils creating museum exhibits to learn about properties of water, using paper circuits to create illuminated food webs, and creating interactive cell models using a Makey Makey.

After reviewing project examples, time was spent introducing the class to several digital technologies through a stations activity. Though digital technologies were not given preference for the project, this activity was an opportunity to have students explore some of the digital tools that encourage invention in the classroom. The class was broken into groups and each group was given ten minutes to explore various digital tools and resources including Scratch, Instructables, Makey Makey, and Circuit Playground (See Appendix A). Preservice teachers farther along in the teacher preparation program facilitated the stations and helped current students explore the new technologies. A handout of useful websites and a place to make notes at each station was also provided (See Appendix B). Students rotated stations such that by the end of the activity they had briefly explored each of the technologies. The final part of the project introduction day was a reflective table talk that occurred after the station activity. At this time, students talked with their classmates and discussed ideas for their final maker project. They were encouraged to connect their project to something they cared about or a specific interest.

Out of class. Students were given two weeks to independently complete their maker projects. Students were free to incorporate traditional skills such as crafts, sewing, knitting, wood working, or metal working in their creation. They were also free to use the digital tools

explored in class, or to combine digital and traditional tools to make something new. There was no additional class time provided however, the instructor and TA were available to help students outside of class. Students were encouraged to upcycle, or creatively reuse materials they already had, in creating their projects. Additionally, students were provided with a list of campus locations where they had free access to fabrication tools such as 3D printers, laser cutters, and sewing machines. The students had access to a workroom with traditional school supplies and a suite of recycled materials. Students could also check out digital tools from the program inventory. All of these items were available to them at no cost.

Presentation and reflection. On the last day of class, students presented their creations via a gallery walk format with half of the class presenting at one time and the other half circulating and serving as the audience. Students in the course produced a wide array of personally significant artifacts each of which told a story about their specific experience. Other preservice teachers, staff, and instructors from the program were invited to the presentations giving each student the opportunity to exhibit their work to a large audience. At the end of the presentation session, students completed a short reflection on making, classroom applications, and the project experience. Complete instructional materials for this maker project can be found at <https://tinyurl.com/maker-final-project>.

Implementation in an elementary science methods course

Elementary Science Methods (ESM) is a required course for all students seeking EC-6 teacher certification at a private liberal arts institution in central Texas. ESM is a 75-minute class that meets twice each week on the university campus in a general science lab. It is offered in the fall semester only and typically enrolls 24 students. Students are predominantly in their final year of the preparation program before student teaching and ESM is one of two science classes required for their graduation from the institution. In the Fall of 2018, there were 23 total students in the ESM course. Twenty-two (96%) of the students in the course were female and one (4%) was male. Two (8%) of the students were sophomores and twenty-one (92%) were either juniors or seniors. Fourteen students (61%) were elementary teaching majors, eight (35%) were special education teacher majors, and the remaining student (4%) was preparing to become a bilingual elementary teacher.

Inspired by the project described above, the ESM maker final project was added to the syllabus three years ago to address specific issues observed from previous semesters of work with elementary science teachers in this context. First, many of the students in prior iterations of ESM had low self-efficacy about their ability to learn and teach science. Thus, one goal for implementing a maker project was to boost student confidence by engaging in a creative activity with a concrete product related to a science concept. Two additional goals relate to the original project from the secondary program: To introduce students to current knowledge around emerging trends in technology and science and to stimulate discussion around the value and challenges of authentic inquiry as a means for student learning and

engagement. Since the act of making requires a personal commitment to the production of a product, the instructor hoped that this activity would enliven student curiosity and demonstrate the value of open-ended projects for their own elementary classrooms.

In class. As with the secondary STEM maker project, this project was framed as a culminating experience introduced near the end of the semester. Similarly, the first day of the lesson began with a video introduction to making. The lesson also included a rotating station activity with a supporting handout. Due to resource availability and focus on elementary school outcomes, the instructor modified the content of the stations. For this iteration, a paper circuits station and a bristlebot station were substituted for the Circuit Playground and Scratch stations. Emphasis was placed on exploration and play at each station and developing a sense of wonder around the materials or ideas. At the end of the class, groups shared what they noticed about the various activities in small groups and the instructor introduced the project options to the class. Students were given a choice to either: a) create a product that documented learning to use a tool or product that would demonstrate its possible usefulness in elementary science, or b) investigate an aspect of making, write a summary of the research, and create a visual product highlighting what they learned.

The second day of the lesson began with a recap of the project criteria. The criteria for this project, while open-ended to allow for authentic, personally meaningful work, included specific elements that related to state standards for elementary science, attention to safety, a projected calendar and a pre-assessment of how project goals and outcomes related to available tools, equipment, and resources to complete the work (see Appendix C). Students were given time to consider potential project options and discuss their ideas with their peers and instructor.

Out of class. Students were provided three weeks to complete the project before the culminating presentation. This timeframe included the Thanksgiving holiday and many students worked on their product at home. During the last week of classes, the students were given an additional class day to share their projects in an unfinished state for feedback, to revise and refine their ideas, and to borrow tools from the supply cabinet for completion.

Presentation and reflection. During the final exam period, student products were set up and shared with peers and instructor in a maker exhibition. As in the secondary setting, the project presentations took place science fair style with half of the students presenting and half serving as the audience at any one time. Students also completed a written reflection discussing challenges, reiterating connections to science standards, and reflecting on lessons learned from the experience.

Insights from Project Implementation

While there was no formal data collection included as part of this project, student products and reflections from each setting provide initial insights. Figure 2 provides an overview of general insights as well as those specific to each context.

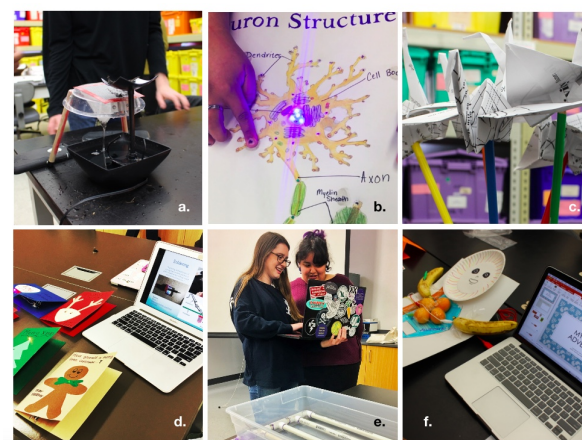
Figure 2 (Click on image to enlarge). An overview of maker project insights.



General Insights

The two contexts for maker project implementation differed significantly. However, insights emerged that were common to both settings. First, in both contexts, the preservice teachers developed a wide range of products including both high- and low-tech creations (see Appendix D). Figure 3 shows: a) a DIY water filtration system; b) an interactive neuron model; c) a series of origami swans; d) soldered paper circuit holiday cards e); a fluidized air bed; and f) an interactive model of a new “teacher” with makey makey fruit controls and related story.

Figure 3 (Click on image to enlarge). A range of student-generated maker projects.



The work produced for this project was personally connected to the interests and motivations of the makers and rooted in the students' own lives. Second, reflections from preservice teachers in both courses indicate that, through this project, many students experienced the importance of persistence and adaptability when encountering challenges. The open-ended

nature of the project turned out to be one of its most important elements as it challenged students develop an original idea and then persist and adapt to bring their idea to life. Third, in both contexts, many preservice teachers described a sense of accomplishment and enjoyment stemming from the creation and presentation of their work. Finally, students in both courses made connections between their maker experience and the process of teaching and learning. Table 2 shows comments from student reflections related to these themes.

Table 2 (Click on image to enlarge)

Student Comments From Both Maker Project Settings

Personally meaningful creations that connect to interests outside of the classroom	
Reflections from Introductory Secondary STEM Teaching Course	<i>It was really fun to talk about the parts of my life that make me who I am and how it influenced me to make the project I did. It was very evident that everyone's experience will influence the way they teach and create.</i>
Reflections from Elementary Science Methods Course	<i>I learned how to solder for the first time and now I can't wait to do it again. Thanks to the opportunity of using making in this class, I can now say I want to learn how to solder to make earrings.</i>
Importance of persistence and adaptability	
Reflections from Introductory Secondary STEM Teaching Course	<i>My experience was very trial and error. I had a plan to make a scribble centipede but after various failures I ended up with a scribble sepiapod. It taught me a lot about adaptability and resilience.</i>
Reflections from Elementary Science Methods Course	<i>This project taught me to be patient, disciplined, and to persevere.</i>
Sense of accomplishment	
Reflections from Introductory Secondary STEM Teaching Course	<i>It was a satisfying experience to think of something, work on it, and then have a physical creation of what was once only in your mind.</i>
Reflections from Elementary Science Methods Course	<i>I know a skill now that I can use for the rest of my life. I was able to impress myself and others.</i>
Connections to teaching and learning	
Reflections from Introductory Secondary STEM Teaching Course	<i>Making is taking an idea and incorporating other aspects to make it tangible. After doing this project, I realized that a lot of learning is in the process rather than the final product.</i>
Reflections from Elementary Science Methods Course	<i>I got very interested in the science behind the fluidized air bed and excited about science. I feel making can help students get excited about something and this feeling is what can help students truly learn.</i>

Additionally, in both settings, the project encouraged some students to take making further. In the secondary setting, multiple students went on to join the maker micro-credentialing program offered by the teacher preparation program. In the elementary setting, several students completed independent projects in the area of making. For example, two students collected data, worked with university faculty and teachers at local makerspaces, and presented their findings on supporting special needs students in making at a local maker education conference.

Insights from an Introductory Secondary STEM Teacher Preparation Course

Written reflections indicate that many members of the secondary STEM teacher preparation course developed a deeper understanding of the nature of making. As an example, one student wrote that “I thought that making was all about electronics and coding but there is so much more...it generates your own creativity and interests.” Another student wrote, “Making is about putting one’s experiences and passions into a project. Making adds a sense of ownership and differentiation.” This was a first exposure to making for most students and their reflections indicate that the project helped them develop a personal conception of what it means to make.

Second, this project helped model the creation of a safe space for exploration and failure for these students. The class mantra during this project was “You can’t get it wrong” and student reflections illustrated their connection with this part of a maker mindset. For example, one student commented, “Making is about growing as an explorer. Making is not being afraid to fail! At the beginning I thought making was trivial but I now see the importance of hands on learning as a chance to really fail.” Another student said, “During creating, I asked myself ‘Am I doing it right?’ ‘Is this fine?’ and when I was presenting I realized ‘this is totally fine, there is no right or wrong’.” This positive message about failure is not one that STEM undergraduates at large public universities often hear. Thus, for this group, the project provided an essential model for rewarding effort over the commonly prioritized final product.

Insights from an Elementary Science Methods Course

The elementary preservice teachers in the three-hour course showed increased confidence with a wide array of maker tools and equipment such as soldering irons, electronics, and woodworking equipment. The open-ended nature of the assignment allowed students in this course to make a range of high-level products, from a 2D model of a neural cell that used different colored LED’s to show how a neural impulse moves, to holiday cards, to a fluidized airbed. Reflections indicate that many students felt increased confidence with equipment related to their projects. One student commented, “I never thought I’d be able to solder, but after connecting the LED’s to the paper circuit holiday cards, I can do it! Thanks for giving me the chance to learn this. I want to try making jewelry next.”

The students in the ESM course also made specific connections to teaching science in the elementary context. Student reflections show that they honed in on ideas of agency and engagement as central features of making that would motivate them to do projects of this kind with their future pupils. For example, one student said, “I am totally going to use making in my science classroom because it makes students take responsibility for their own learning and gives them ownership of their work.” Another student wrote, through making “you can make science fun and creative for students allowing them to take control of creating whatever they can dream of.” These reflections illustrate the potential of this project to influence the classroom instruction of these future teachers.

Finally, one unique outcome was that many members of the elementary group experienced making as an opportunity to create with friends and family. The project implementation in this setting coincided with the Thanksgiving holiday, giving many students the opportunity to work with parents or friends. For example, one student shared the specifics of her maker journey with permission. When the project was introduced, she considered making something for her father as a holiday gift. She initially wanted to learn how to create fly-fishing flies based on her father’s love of fishing. However, the costs of buying materials were prohibitive. A chance visit to a website that showed a video demonstrating the non-Newtonian nature of a fluidized airbed then excited her to consider making her own model to demonstrate this fascinating phenomenon. After checking that the proper equipment to make a small model

was available in her family garage, she traveled home for Thanksgiving with initial instructions. She worked with her father over the break to bring her creation to life. Like many maker projects, the initial results required refinement. Challenges included compressor issues as well as using the wrong substrate for the bed material. However, she persisted and was able to present her model at the maker exhibition with pride. The student's build is documented in this [video](#). It highlights her energy and enthusiasm for the work. She recently shared with Steve that she will be refining her initial attempt again, having secured a bigger compressor and better substrate.

While making is a journey that differs for each maker, many of the students in the ESM class included a significant other in their building process. This was an unexpected outcome and may have led to more collaborative and ambitious creations. This insight highlights the potential of making as a community-building endeavor.

Project Management

It should be noted that some students were challenged by the technical details and time required to produce a working product so it is important to provide extended time and to include out of class support. This might include additional office hours and partnering with more advanced students to provide technical support. Consider working with campus engineering, art, or instructional technology departments to find others willing to help with advice on construction and tool use. In addition, instructors should consult with appropriate university departments concerning risk management strategies to ensure student safety. Requiring students who plan to use equipment with potential risk in their projects (woodworking or metalworking equipment for example) to complete safety training is highly recommended. The Occupational Safety and Health Administration provides guidelines for safe hand and power tool use (OSHA, 2002).

Regular check-ins with students are also useful. Instructors implementing this type of activity might encourage students to complete weekly reflections and upload photos to document the evolution of their process. Including documentation practices of this kind models the use of electronic platforms, such as Blackboard or Canvas, now common in many school districts, as portfolio systems that can be used to capture and share the ongoing work of their K-12 pupils.

Discussion

The culminating maker project was an open-ended assignment where students were invited to: a) make an artifact related to STEM teaching; b) present their product publicly; c) reflect on their work; and d) consider classroom applications. In the process of creation and making, the students explored new digital, craft, and construction technologies and created a product of personal significance. Through making, students in the class experienced fundamental aspects of creativity, agency, persistence, and reflection. These attributes are essential

elements of 21st century learning and are traits that early-career K-12 science teachers are expected to model and train their own pupils to embody. Furthermore, when students integrate scientific practices, disciplinary core ideas, and crosscutting concepts in the authentic products they create, then maker-centered instruction can facilitate NGSS three-dimensional learning principles in a personally meaningful way (National Research Council, n.d.).

This open-ended maker project is adaptable to varied contexts thus, the expertise and goals of the instructor or facilitator will likely shape the student experience. For example, in this project, students reflected on their growth as educators but with a different set of criteria in each setting. For the secondary students who were majoring in a STEM field, self-efficacy around science content was not an issue. Because the course was only one-credit hour, creativity and effort producing an open-ended product was emphasized. Additionally, the TA for this course was well-versed in maker-related electronics and provided extra support to students attempting novel projects with these tools. In the Elementary Science Methods course, the instructor focused on connections to science standards and building confidence in the use of basic tools, with which he had extensive experience. Thus, this project can be used to achieve a wide array of outcomes and instructors should be thoughtful about their project aims from the start, paying special attention to providing a wide range of practice, play, and examples from the maker world. Connecting to local makers, artisans, and craftsman can expand the project's reach.

Furthermore, in both courses, equitable teaching and learning are addressed during other activities. However, because making is often situated in a privileged and gendered paradigm (Vossoughi, Hooper, & Escudé, 2016), future iterations of this activity could include an element that explicitly examines how students can negotiate the opportunities and challenges of the activity in diverse classroom settings. Explicit reflections on equity and readings on these issues as they relate to maker education would be productive additions for future iterations.

Conclusion

Tenacity in the face of adversity is a common trait among successful teachers who must evaluate and adapt their teaching to new situations on a daily basis, and who undoubtedly fail many times but use those failures to learn and grow. In the same way, this culminating maker project was scary, messy, exciting, and inspiring. While student projects rarely turned out as planned, student reflections suggest that the experience helped them to value and embrace this ill structured process. As future teachers, this maker experience may be critical in helping our newest practitioners envision a classroom space where students are personally connected to content, have ownership of their learning, are given the freedom to explore and create without fear, and are encouraged to persist in the face of challenges. In

this way, including a project that addresses elements of making and fosters a maker mindset can be a valuable step toward preparing preservice teachers to bring innovative and inspirational practices to science education.

Acknowledgement

This article was developed in connection with the UTeach Maker program at The University of Texas at Austin. UTeach Maker is funded in part by a Robert Noyce Teacher Scholarship grant from the National Science Foundation (1557155). Opinions expressed in this submission are those of the authors and do not necessarily reflect the views of The National Science Foundation.

References

- Bevan, B. (2017). The promise and the promises of making in science education. *Studies in Science Education*, 53(1), 75-103. doi:10.1080/03057267.2016.1275380
- Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). *Maker-centered learning: Empowering young people to shape their worlds*. San Francisco, CA: Jossey-Bass
- Cohen, J. (2017). Maker principles and technologies in teacher education: A national survey. *Journal of Technology in Teacher Education*, 25(1), 5-30. Retrieved from <https://www.learntechlib.org/p/172304>
- Fields, D. A., Kafai, Y., Nakajima, T., Goode, J., & Margolis, J. (2018). Putting making into high school computer science classrooms: Promoting equity in teaching and learning with electronic textiles in exploring computer science, *Equity & Excellence in Education*, 51(1), 21-35. doi:10.1080/10665684.2018.1436998
- Halverson, E. R., & Sheridan, K. M. (2014). The maker movement in education. *Harvard Educational Review*, 84, 495-504. doi:10.17763/haer.84.4.34j1g68140382063
- High Quality Project Based Learning (HQPBL) (2018). *A framework for high quality project based learning*. Retrieved from <https://hqpbl.org/wp-content/uploads/2018/03/FrameworkforHQPBL.pdf>
- Make. (March 30, 2016). What is a maker? [Video file]. Retrieved from <https://www.youtube.com/watch?v=rUoZwuSDikY>
- Maker Education Initiative (n.d.). *Approach*. Retrieved from <http://makered.org/about-us/approach/>
- Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research*, 5(1), 30-39. doi:10.7771/2157-9288.1099

Menon, D., & Sadler, T. D. (2016). Preservice elementary teachers' science self-efficacy beliefs and science content knowledge. *Journal of Science Teacher Education*, 27, 649-673. doi:10.1007/s10972-016-9479-y

National Research Council (NRC). (n.d.). Three Dimensional Learning. Retrieved from <https://www.nextgenscience.org/three-dimensions>

National Science Foundation (NSF). (2017). *The National Science Foundation and making*. Retrieved from https://www.nsf.gov/news/news_summ.jsp?cntn_id=131770

National Science Teacher Association (NSTA). (2013). *Science and engineering practices*. Arlington, VA: Achieve, Inc. Retrieved from <http://static.nsta.org/ngss/MatrixOfScienceAndEngineeringPractices.pdf>

Papert, S. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 1-11). Norwood, NJ: Ablex Publishing Corporation.

Peppler, K., Halverson, E., & Kafai, Y. B. (2016). Chapter 1: Introduction to this volume. In K. Peppler, E. Halverson, & Y. B. Kafai (Eds.), *Makeology: Makerspaces as learning environments* (Vol. 1, pp. 1-11). New York, NY: Routledge.

Rice, D. C., & Roychoudhury, A. (2003). Preparing more confident preservice elementary science teachers: One elementary science methods teacher's self-study. *Journal of Science Teacher Education*, 14, 97–126. doi:10.1023/A:1023658028085

Rodriguez, S., Harron, J., Fletcher, S., & Spock, H. (2018). Elements of making: A framework to support making in the science classroom. *The Science Teacher*, 85(2), 24-30.

Rodriguez, S. R., Harron, J. R., & DeGraff, M. W. (2018). UTeach Maker: A micro-credentialing program for preservice teachers. *Journal of Digital Learning in Teacher Education*, 34(1), 6-17. doi:10.1080/21532974.2017.1387830

Qi, J., & Buechley, L. (2010, January). Electronic popables: Exploring paper-based computing through an interactive pop-up book. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction* (pp. 121-128). ACM.

Qi, J., & Buechley, L. (2014, April). Sketching in circuits: Designing and building electronics on paper. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1713-1722). ACM.

Stager, G., and Martinez, S. L. (2013). *Invent to learn: Making, tinkering, and engineering in the classroom*. Torrance, CA: Constructing Modern Knowledge Press.

Tofel-Grehl, C., Fields, D., Searle, K., Maahs-Fladung, C., Feldon, D., Gu, G., & Sun, C. (2017). Electrifying engagement in middle school science class: Improving student interest through e-textiles. *Journal of Science Education and Technology*, 26, 406-417.

Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review*, 86, 206-232. doi:10.17763/0017-8055.86.2.206

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice?. *Science education*, 87(1), 112-143. doi:10.1002/sce.10044

Yoon, S., Pedretti, E., Pedretti, L., Hewitt, J., Perris, K., & Van Oostveen, R. (2006). Exploring the use of cases and case methods in influencing elementary preservice science teachers' self-efficacy beliefs. *Journal of Science Teacher Education*, 17, 15–35. doi:10.1007/s10972-005-9005-0