2021

You Want Me to Teach Engineering? Impacts of Recurring Experiences on K-12 Teachers' Engineering Design Self-Efficacy, Familiarity with Engineering, and Confidence to Teach with Design-Based Learning Pedagogy

Shaunna Smith

University of Hawai'i, shaunna.smith@hawaii.edu

Kimberly Talley

Texas State University, talley@txstate.edu

Araceli Ortiz

Texas State University, araceli@txstate.edu

See next page for additional authors

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Recommended Citation

Smith, S., Talley, K., Ortiz, A., & Sriraman, V. (2021). You Want Me to Teach Engineering? Impacts of Recurring Experiences on K-12 Teachers' Engineering Design Self-Efficacy, Familiarity with Engineering, and Confidence to Teach with Design-Based Learning Pedagogy. *Journal of Pre-College Engineering Education Research (J-PEER)*, 11(1), Article 2.

<https://doi.org/10.7771/2157-9288.1241>

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Document Type

Research Article

Authors

Shaunna Smith, Kimberly Talley, Araceli Ortiz, and Vedaraman Sriraman

Journal of Pre-College Engineering Education Research 11:1 (2021) 26–41

You Want *Me* to Teach Engineering? Impacts of Recurring Experiences on K-12 Teachers' Engineering Design Self-Efficacy, Familiarity with Engineering, and Confidence to Teach with Design-Based Learning Pedagogy

Shaunna Smith¹, Kimberly Talley², Araceli Ortiz², and Vedaraman Sriraman²

¹*University of Hawai'i*

²*Texas State University*

Abstract

This paper reports on findings from a group of ten teachers who were enrolled in a semester-long, graduate-level educational technology course that used design-based learning to explore the integration of making and the engineering design process into a variety of K-12 educational contexts. Using convergent mixed methods, this study examines how the course impacted teachers' familiarity and confidence in teaching the engineering design process, as viewed through their pre- and post-semester engineering design self-efficacy scores and their weekly reflective journal entries. These measures are important factors for developing teacher experience and confidence in integrating engineering and design-based learning strategies within K-12 educational contexts. Statistically significant results include increased confidence in design and decreased anxiety toward design. Findings illustrate how participants acknowledged increased familiarity and confidence in teaching the engineering design process, including their increased ability to make connections to the engineering design process, maker tools, and techniques. Implications for teacher education programs are discussed.

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Engineering Confidence: Impacts of Recurring Design-Based Learning Experiences on Teachers' Engineering Design Self-Efficacy

Engineering concepts are integrated throughout the Next Generation Science Standards (NGSS) as a means to strengthen scientific understanding for kindergarten through Grade 12 (K-12) students in the United States. These science standards include the guidance of students towards engaging in a problem-solving and innovative design process called the Engineering Design Process (EDP) and a set of enacted approaches to learning science and engineering called the Science and Engineering Practices. In addition, the NGSS recommend a specific set of content topics related to engineering, technology, and applications of science disciplinary core ideas (Willard, 2014). The need for these new science standards stands out for their inclusion of engineering as described above and are intended not only to describe a suggested science roadmap for students, but also to highlight a professional development program for teachers. Hynes et al. (2017) conducted a systematic review of engineering education research publications spanning 2000–2015 and found that approximately 50 published studies report that K-12 teachers without prior experience range significantly in their understanding of

engineering concepts and confidence in integrating engineering concepts into their classroom teaching. Thus, it is important to identify and research the potential impact of new professional development approaches that might assist teachers to bridge this technological literacy gap. Engineering educators and teacher educators assert that *making* can be used as a novel strategy to promote science, technology, engineering, and mathematics (STEM) and integrate engineering into K-12 learning contexts (Martin, 2015; Thomas & Besser, 2017).

Making is exactly what it sounds like—designing, creating, and building—but the term has also been adopted and associated with the activities that take place in a designated physical space where creative humans gather to share resources and ideas while learning and working together on projects. Various types of tools can be used for making, which range from very basic paper and scissors, wood/metal/fabric shop tools, and on to advanced three-dimensional (3D) printers and other high-tech tools (Martinez & Stager, 2013; Peppler et al., 2016). Making has become popular in K-12 education for its ability to connect do-it-yourself (DIY) crafting practices with creative design and the application of multidisciplinary concepts (Peppler et al., 2016). Despite potential educational benefits, researchers, such as Blikstein (2013), Clapp et al. (2017), Martin (2015), and Vossoughi et al. (2016), encourage educators to pay attention to the learning potential within the *process* of making because merely focusing on a tool or technology will not result in meaningful integration. Similarly, Hynes et al. (2017) indicate that teachers cannot effectively integrate the engineering design process into their classroom without proper experience of engaging in it themselves. In order to help teachers grapple with the new pedagogical strategies necessary to meaningfully integrate making and engineering into the K-12 classroom, researchers must examine the ways in which teachers can be supported to gain experience and self-confidence with engaging in the design process and the technical skills needed to support student learning.

Studies of short-term maker experiences for teacher professional development show positive engagement and interest (Jones et al., 2017; Paganelli et al., 2016). However, many of these studies also highlight teacher misconceptions such as the requirements for expensive technologies, perceived difficulty connecting the technologies to K-12 learning objectives (Cohen et al., 2018), and a general struggle to work within the open-ended, nontraditional structure of making and makerspace environments (O'Brien et al., 2016; Paganelli et al., 2016). Of the few long-term studies on maker experiences for teacher professional development, researchers note that recurring experiences and opportunity to engage in reflective practice encouraged teachers to see the power of collaborative learning and begin to see more clear connections to K-12 classroom content (Cohen et al., 2017; Jones et al., 2019; Ortiz et al., 2018). Due to the lack of research available on the integration of making and engineering in teacher education, there is a need for more longitudinal studies that examine best practices for the design of these recurring learning experiences and the impacts on teacher self-efficacy.

This paper reports on findings from a study with a group of ten teachers who were enrolled in a semester-long, graduate-level educational technology course that used design-based learning to explore the integration of making and engineering design process into a variety of K-12 educational contexts. This course included recurring design experiences with diverse design topics that incorporated a variety of engineering concepts, non-digital and digital tools, techniques, and materials. The purpose of this convergent mixed-methods study was to examine how engaging in this course impacted teachers' familiarity and confidence in teaching the engineering design process, as viewed through their pre-/post-semester engineering design self-efficacy and their weekly reflective journal entries. These measures are important factors for developing teacher experience and confidence in integrating engineering and design-based learning strategies within K-12 educational contexts. This paper presents relevant literature regarding teacher self-efficacy, making in teacher education, design-based learning, and engineering design self-efficacy. Mixed-methods results and findings are presented followed by a discussion of implications for teacher education.

Literature Review

General Self-Efficacy and Engineering Design Self-Efficacy

Social cognitive theory developed by Bandura (1977, 1997) provides the theoretical foundation for self-efficacy. According to this theory, individuals motivate their own behavior and development rather than being driven by external forces or controlled by their environments (Bandura, 1989). Bandura (1997) defines self-efficacy as the belief in one's capabilities to organize and execute the courses of action to produce given attainments. Other scholars in the field maintain that behavior and behavioral change are primarily mediated by self-efficacy beliefs (Henson, 2001). In a related manner, teaching self-efficacy refers to the beliefs that teachers hold about their capabilities as teachers. These teaching capabilities refer to the general abilities as an educator but can be further identified by area of instruction such as mathematics education self-efficacy, science education self-efficacy, and engineering design self-efficacy. Teacher self-efficacy has been defined as a teacher's judgement of his or her capabilities to bring about desired outcomes of student engagement and learning, even amongst those students who may be difficult or unmotivated (Tschannen-Moran et al., 1998). In a study of elementary

school teachers, it was found that teachers' engineering self-efficacy and their engineering teaching self-efficacy were associated (Hammack & Ivey, 2017). Experimenting with instructional methods, seeking improved teaching methods, and experimenting with instructional materials are attributed to teachers with high teaching efficacy (Allinder, 1994; Guskey, 1988; Stein & Wang, 1988). Teacher self-efficacy has been identified by researchers to be a strong predictor of teacher job satisfaction and intention to persist in the profession (Klassen & Chiu, 2010; Skaalvik & Skaalvik, 2010).

Bandura's social cognitive theory provides the common basis for studying both teacher self-efficacy and engineering design self-efficacy. Researchers have suggested that in addition to measuring engineering design self-efficacy in engineering-related domains such as mathematics and science, such measurement should also occur in engineering's distinct context to capture the experiences unique to this domain (Mamaril, 2014). Engineering education research has identified several engineering-specific skills that students should possess to be successful as engineers (Mamaril, 2014). Tinkering and making skills are included amongst these skills, which are employed in creating and modifying products, and are crucial for engineers (Baker et al., 2007). Singer et al. (2016) studied strategies, tools, and techniques that might be effectively used to integrate engineering in high school STEM classrooms. Furthermore, Hammack & Ivey's (2017) study showed that elementary school teachers' engineering teaching self-efficacy, their engineering and design experience levels, and their engineering design self-efficacy scores were all positively correlated. Therefore, we maintain that in order for teachers to prepare their own students to confidently engage in design and making in the classroom, they must first go through the process of becoming confident in their own design and making self-efficacy.

Making in Teacher Education

Buechley (2013) and Vossoughi et al. (2016) caution educators to critically consider the values, goals, and meanings of making, including how terms such as "maker," "making," and "makerspace" are defined and the inclusion or exclusion of non-STEM content areas (i.e., arts and humanities) within the STEM-centric narrative. Blikstein (2013), Buechley (2013), Martin (2015), and Vossoughi et al. (2016) also highlight the prevalence of capitalist branding among the maker movement and a focus on expensive technologies that promote a myth that making is only for those who have access to fancy tools. Through extensive longitudinal research in diverse educational settings, Clapp et al. (2017) have identified maker-centered learning as a theoretical framework that leverages components of making to support student empowerment and sensitivity to design.

Making and makerspace practices are often introduced to teachers through one-time workshop experiences. Cohen et al. (2018) conducted a series of one-time maker education workshops with 82 in-service and pre-service teachers and analyzed post-reflections to find two major misconceptions, including the belief that (1) making in education consisted of hands-on activities only designed to achieve specific content learning objectives and (2) making is largely dependent on the use of expensive advanced manufacturing tools, such as 3D printers. Similar findings were reported by other researchers who conducted one-time maker education experiences and found that teacher participants struggled with misconceptions and the nontraditional, open-ended structure of making (O'Brien et al., 2016; Paganelli et al., 2016). Jones et al. (2017) found that teacher participants identified perceived barriers but expressed favorable attitudes toward implementing maker activities in their future classrooms and noted these tools and activities aligned with instructional strategies encouraged in their teacher preparation programs, including problem-based learning, inquiry learning, and hands-on learning activities.

Though there are a growing number of maker-related programs being offered across the country to raise awareness for makers and maker educators (Hsu et al., 2017), a recent national survey indicates that maker integration within teacher education programs is not widespread (Cohen, 2017). In a study of a recurring semester-long maker education experience with 13 teachers, Cohen et al. (2017) found that when making was presented through recurring activities, the participants viewed the related learning as a more collaborative experience and noted confidence in the benefits that integrating making could have on a K-12 classroom learning environment. More research is needed in this area to examine and share best practices for increasing teacher self-efficacy in integrating making and makerspaces within the K-12 context.

Design-Based Learning

Design-based learning (DBL) is a type of problem-based instructional model that highlights an iterative design cycle as learners investigate and explore content concepts while actively engaging in design and redesign (Kolodner, 2002). This strategy can be used in maker environments to support a systematic engineering design process and deeper content learning through engaging in the hands-on design of artifacts. Due to the multidisciplinary, problem-focused approach, DBL is an effective instructional model for integrating engineering concepts into the classroom (Gómez Puente et al., 2015). As with most problem-based learning approaches, the instructional structure of DBL encourages active participation, creative problem-solving, personal connections to learning, multidisciplinary connections, a sense of audience, and a space for

reflection and discussion (Kafai et al., 2009; Resnik et al., 1999). Bekker et al. (2015) promote DBL as the iterative design of creative artifacts, which involves development, building, evaluation, and recurring reflection. DBL activities can be presented using a variety of approaches, including asking learners to engage in design to produce solutions to problem-focused challenges (Hmelo et al., 2000; Nelson, 2004) or engage in design to express themselves while they gain deeper understanding of content concepts and/or creatively experiment with materials (Petrich et al., 2013; Ryan et al., 2016).

As learners engage in DBL they are actively engaged in a design process and learning can be enhanced if educators facilitate thoughtful questions that prompt reflection. Similar to the holistic design process used in visual arts to design personal artistic expressions or visual solutions, the engineering design process is a cyclical and iterative process that assists engineers and designers in the complex act of designing new products to address constraints and solve problems (Hynes, 2012; Ullman, 2003). The steps in the engineering design process are similar to the concept of “design thinking,” which is a core element of human-centered design and creative problem-solving widely used in the arts, business, and educational contexts (Buchanan, 1992; IDEO, 2013; Norman, 2002). The Engineering is Elementary (EiE) engineering design process (Engineering is Elementary, 2020) is a widely used model that includes an easy-to-understand five-step simplified procedure:

1. **ASK:** *What is the problem? How have others approached it? What are your constraints?*
2. **IMAGINE:** *What are some solutions? Brainstorm ideas. Choose the best one.*
3. **PLAN:** *Draw a diagram. Make lists of materials you will need.*
4. **CREATE:** *Follow your plan and create something. Test it out!*
5. **IMPROVE:** *What works? What doesn't? What could work better? Modify your design to make it better. Test it out!*

The EiE engineering design process guides students in a systematic process and terminology that children can easily understand, apply, and discuss (Aguirre-Muñoz & Pantoya, 2016; Oh et al., 2016). This makes it very useful for teachers who do not have a formal engineering background (Cunningham & Carlsen, 2014; Lottero-Perdue & Parry, 2015).

This study will explore the ways that engagement in a making-focused course impacts participants' engineering design self-efficacy as well as familiarity with and confidence to teach the engineering design process.

Method

This paper reports on the experiences of ten teacher participants who were enrolled in a semester-long, graduate-level educational technology course that used DBL to explore the integration of making and engineering design process into a variety of K-12 educational contexts. The course spanned 15 weeks and included 45 contact hours. A convergent mixed-methods design was used, which included quantitative and qualitative data that were collected separately, analyzed separately, reported separately, and ultimately converged for triangulation, comparison, contrasting, and interpretation (Creswell & Plano Clark, 2018). Data collected included the Engineering Design Self-Efficacy (EDSE) survey instrument (Carberry et al., 2010) and text entries from weekly reflective journal entries.

Participants

Participants included 10 teachers (6 females and 4 males; 7 in-service teachers and 3 pre-service teachers seeking initial certification) who were enrolled in a graduate-level educational technology course at a large Hispanic-serving institution in the southwestern United States. All participants were assigned pseudonyms for the purposes of this research. Table 1 provides participant demographics, including gender, number of years of teaching experience, grade level taught, content area taught, and whether or not they had prior making experience.

Context of the Course

The semester-long, graduate-level educational technology course was designed and taught by the first author, who served as a participant observer. The course took place as a part of the Educational Technology Master's program coursework in the College of Education's Department of Curriculum & Instruction. The course was developed with the intention to introduce maker education and engineering design process to in-/pre-service education majors from a variety of personal backgrounds, content area foci, and grade level foci. Scaffolding and activities designed for this course were based on theoretical recommendations from Vossoughi et al.'s (2016) equity-oriented research and design for integrating making, which included the following attempts:

1. specific introduction of non-digital tools and free or low-cost maker technologies that were easily accessible for a variety of K-12 education populations;

2. scaffolding non-digital techniques prior to introduction of new maker technologies and tools in order to provide thoughtful connections to existing and historical cultural craft techniques;
3. explicit attention to hands-on “learning by doing” constructionist pedagogies (Papert & Harel, 1991) and reflective formative assessment strategies that emphasized process in addition to final artifact products; and
4. on-going discussion of diverse purposes for making, including direct application of engineering and content standard connections, personally meaningful creative expression, experimentation, and problem-solving.

The course included an exploration of the following topics: 2D design (i.e., free vector-based software, paper/vinyl cutting, pop-up card creation, sewing and embroidery), 3D design (i.e., modeling clay, free 3D CAD software, 3D scanning, 3D printing), simple electronics (i.e., LED lights and motors, interactive design for microcontrollers), and visual-based computer programming (i.e., Scratch, Scratch Jr.). Though most of the activities took place in the classroom makerspace specifically designed to enable education majors to explore maker tools and techniques, participants in the course also had access to the collaborative university makerspace that had larger equipment (i.e., laser/engraving machine, large-format 3D printers, digital sewing and embroidery machine).

Survey Instrument Data Collection and Analysis

Carberry et al.’s (2010) EDSE instrument uses an eleven-point Likert scale (0, 10, ..., 100) to evaluate engineering design self-efficacy through four lenses: confidence, motivation, expectation of success, and anxiety. This instrument has been used to measure the engineering design self-efficacy of diverse participants including in-service teachers and undergraduate students of varying levels of non-engineering and engineering backgrounds (Gerber et al., 2012; Hammack & Ivey, 2017; Hilton et al., 2020). The survey was administered at the beginning of the first class meeting (August) and at the end of the final class meeting (December). An overall design self-efficacy score was calculated by reverse scoring the anxiety results and then averaging these four group totals. Additional validity included analyzing the results associated with each lens separately by correlating the lens’ Engineering Design (ED) score, which is the student response to the first statement in the lens, “conduct engineering design,” in correlation to the EDP score. The EDP score is the average of student responses to each of the other eight elements of engineering design in the instrument, such as “Identify a design need” and “Redesign.” The complete list of nine statements in each lens of the EDSE is presented in Appendix A. Using Pearson correlation, the ED and EDP scores were compared for their correlation in each lens for both the pre- and post-tests. Finding a correlation between these scores, the ED was then used for additional analysis (Carberry et al., 2010). The pre-semester survey (pre-test) and post-semester survey (post-test) ED scores for each lens of the EDSE were compared with a one-tailed, Wilcoxon signed-ranks test to assess statistical significance of the percentage change between these results. Wilcoxon signed-ranks tests were selected to specifically measure the changes in students who completed both the pre-test and post-test ($n = 7$) as it is especially effective for data with a small sample size (Pett, 2016). The effect size, r , is also calculated for each of these paired tests (Field, 2018). As such, the descriptive statistics for pre- and post-tests are also reported for the students who took both tests to most accurately represent the quantitative changes that resulted from this semester-long (15 weeks) study.

Table 1
Participant demographics.

Participant	Gender	Years of teaching experience	Grade level	Content	Prior making experience
Dustin	M	25	9–12	Technology	Y
Jacob	M	14	9–12	Social studies	N
Jett	M	4	9–12	Social studies	N
Linda	F	12	6–8	Language arts	N
Maggie	F	3	3	Language arts	Y
Michelle	F	6	9–12	Foreign languages	Y
Rachel	F	Pre-service	K-5	All	Y
Robert	M	2	6–8	Mathematics	N
Tabitha	F	Pre-service	K-5	All	N
Tammy	F	Pre-service	9–12	Health sciences	N

Weekly Reflective Journal Data Collection and Analysis

Weekly reflective journal entries were posted by each of the participants to an online course forum (i.e., secure Edmodo group website) and included (1) a guiding prompt related to the weekly class topic (e.g., digital fabrication software and hardware, subtractive manufacturing, additive manufacturing, textiles, simple electronics, interactive microcontrollers, computer programming), (2) design process documentation (e.g., original photograph or video clip that represented personal engagement in the design process or completed artifact), and (3) “exit ticket” response (i.e., three things they learned during the in-class activities, two things they wanted to learn more about, and one thing they were confused about).

Weekly reflective journal entries were collected each week for a total of 15 weeks, and then entries were uploaded and coded using NVIVO qualitative data analysis software. Using qualitative techniques described by Miles et al. (2014), the data were analyzed in two cycles by two researchers. During the first cycle, the two researchers independently coded two of the participants’ reflections using deductive coding based on terms associated with self-efficacy, design, making, and engineering design process. Inter-rater reliability was measured in NVIVO using Cohen’s kappa (Cohen, 1960), which was 0.65 and is considered fair to good agreement. Both researchers met to debrief, which included comparing and discussing their independently coded data, and verifying, modifying, and/or refining codes until agreement was met. Inter-rater reliability was measured a second time in NVIVO using Cohen’s kappa (Cohen, 1960), which was 0.85 and is considered excellent agreement. The remaining data were distributed amongst the two researchers for the second cycle of analysis, in which data were constantly compared and reanalyzed for new codes, categories, and emergent themes.

Results and Findings

Results and findings are presented to show quantitative pre- to post-test changes in engineering design self-efficacy, qualitative data acknowledging familiarity with and confidence to teach the engineering design process, including connections to the engineering design process, and qualitative data acknowledging connections to maker tools and techniques.

Pre- to Post-Test Changes in Engineering Design Self-Efficacy

As per Carberry et al. (2010), a Pearson correlation would normally be used to compare the ED and EDP scores in each of the four lenses of the EDSE instrument. As this dataset was small versus Carberry et al. (2010), the nonparametric Spearman rho (also known as the Spearman rank-order correlation) was used to compare ED and EDP scores. The results of these correlation tests are presented in Table 2 (Pett, 2016). Notably, the correlations were lower in the pre-tests than the post-tests (see Table 2). These correlations are often 0.8 and above when administered to engineering or engineering technology majors, who can be assumed to have engaged in the engineering design process previously (Hilton et al., 2018; Morocz et al., 2016; Tsenn et al., 2013). Therefore, it is hypothesized that these lower pre-test correlations and higher post-test correlations could be due to the teacher participants being novices to the engineering design process at the start of this course and their growth in understanding as they more clearly understood the engineering design process by the end of the semester, resulting in more accurate self-reporting.

Secondly, one-tailed, Wilcoxon signed-ranks tests were used to compare the pre-tests and post-tests for each lens looking for statistical significance in the difference over the course of time. There are two lenses with statistical significance in their change, Confidence and Anxiety, as well as the overall engineering design self-efficacy score. These differences all have medium to large effect sizes (0.54, -0.54 , and 0.50, respectively) (Field, 2018). Even the change in teacher expectation of success has a medium to large effect size (Field, 2018), despite the difference not being statistically significant. Teacher participants in this study saw a 92.3% increase in their confidence to engage in the design process and a 46.9% reduction in their anxiety toward the design process. Participants expressed a 41% increase in their overall engineering design self-efficacy (see Table 3 and Figure 1).

Table 2
Spearman rho correlation between in-/pre-service teachers’ ED and EDP scores.

	Confidence	Motivation	Success	Anxiety
Pre-test (August)	0.62	0.88	0.77	0.52
Post-test (December)	0.82	0.96	0.96	0.91

Table 3

Changes in in-/pre-service teacher engineering design self-efficacy.

	Confidence	Motivation	Success	Anxiety	Overall ^a
Pretest (Aug 2016), M (SD)	37.14 (28.70)	70.00 (20.00)	60.00 (16.33)	70.00 (29.44)	49.29 (17.78)
Post-test (Dec 2016), M (SD)	71.43 (15.74)	72.86 (22.15)	71.43 (22.68)	37.14 (24.30)	69.64 (18.51)
Change (%)	92.3	4.1	19.0	-46.9	41.3
Wilcoxon signed-ranks result	$z = 2.00$, $p = 0.023^{**}$	$z = 0.00$, $p = 0.500$	$z = 1.58$, $p = 0.057$	$z = -2.02$, $p = 0.022^{**}$	$z = 1.86$, $p = 0.031^{**}$
Effect size, r	0.54	0.00	0.42	-0.54	0.50

^aOverall design self-efficacy uses a reverse scoring of the Anxiety construct.^{**}Results with statistical significance at the 0.05 level.

Figure 1. Pre-test and post-test comparison of average engineering design self-efficacy results.

Acknowledging Familiarity With and Confidence to Teach the Engineering Design Process: Connections to the Engineering Design Process and Making

Throughout the 15-week experience, many participants provided examples in their weekly reflective journal entries that demonstrated changes to their preconceived values, goals, and understanding of the engineering design process as well as an acknowledgement of connections to the engineering design process. Their reflections revealed an increased confidence in engaging in the design process as well as an awareness of their own skills and competence. Likewise, the participants' ability to identify similarities to other learning processes positively influenced their appreciation for the learning potential within the engineering design process.

Increased confidence in engaging in the engineering design process

Many weekly reflective journal entries revealed statements that related to the participants' growing confidence in engaging in the engineering design process (and subsequent reduction in anxiety toward engaging in design). Several participants were already somewhat confident in their belief of the learning potential of a maker environment; however, their confidence with communicating the purpose of and the application of the engineering design process grew over time. During week one, Jett noted that one of his biggest personal barriers was "hesitance to claim expertise because my skill level in art(s) is very limited." Similarly, Maggie noted in week one that the pure open-endedness of creative possibilities might be a barrier because "Some of my kiddos need a right and wrong solution. It could potentially drive them crazy having these scenarios without one correct solution." As the semester went on, both Jett's and Maggie's confidence grew with more hands-on experiences involving the engineering design process, including organic conversations with their classmates. Later, Jett reflected that he "felt like a creative problem-solving genius" after successfully completing a

slide-together puzzle challenge during week three. And Maggie reflected in week eight that she “felt invigorated with instructional ideas to help scaffold open-ended learning” with her students.

Tammy, a health sciences teacher, is a standout example of a participant whose confidence in the engineering design process increased over the 15-week experience. She began the semester very uncertain of her individual creative abilities as a maker:

I feel the personal barrier would be my own lack of experience and knowledge using various makerspace technologies. My lack of confidence in this area would cause me to question which tools would work best for my health science curriculum. Basically, I don't know where would I begin. (Tammy, week 1)

But by week 13, she was creating elaborate electrical circuits using copper tape and alligator clips to connect a MaKey MaKey microcontroller and a Scratch program she had remixed to create an “Operation” game (see Figure 2).

Identifying similarities to other learning processes

Several students began to express growing comfort with the engineering design process as they likened it to other processes that they used more regularly. Linda stated:

During makerspace work time students are working on problem solving, thinking about design and creating an end-product, and reading/researching how to make their chosen project. The time spent making supports the processes of iteration: a process we see often in writing, scientific experimentation, and mathematical problem solving.

Similarly, Jake reflected that the engineering design process was similar to instructional design. He stated:

You're confronted with a tough topic to teach so you brainstorm ideas and begin drafting activities to see what it might look like. Some activities seem better than others, so you revise, and you implement it with the students and have formative assessments to see if your instructional solution is working or not.

This way of thinking about “precise designs to solve specific problems” (Jett, week five) was also reflected as participants expressed an essential understanding of process and the powerful role it plays in creating successful designs, regardless of the medium.

Acknowledging Familiarity With and Confidence to Teach the Engineering Design Process: Curricular Connections to Maker Tools and Techniques

Participants began to acknowledge their gaining familiarity and confidence to teach engineering design process through descriptive recognition of broad connections to curriculum using maker tools and techniques. As per suggestions from relevant literature, the course structure purposefully scaffolded non-digital techniques and digital technologies; however, interpretations of the educational uses for each technology were left to be explored by the participants in an open-ended inquiry approach. Weekly reflections indicated that as participants gained experience using maker tools and techniques, they were also able to identify engineering applications, cross-disciplinary connections, and non-engineering curricular uses.

Figure 2. Tammy's homemade “Operation” game using copper tape, aluminum foil, alligator clips, a MaKey MaKey, and Scratch program. Left: exterior of game; right: interior of game.

Figure 3. Jake's 3D scan of miniature statue.

Identifying cross-disciplinary connections while using maker tools and techniques

After experimenting with the first category of tools and techniques (i.e., 2D digital fabrication tools; Silhouette Studio software, Silhouette Cameo paper/vinyl cutting machine, laser engraving machine), participants began to take note of examples they saw in everyday life (e.g., papel picado, pop-up books, product packaging, laser-cut clothing and jewelry) and they began to express ideas for how these tools and techniques could be embedded within curricular content areas. Though skeptical at first, Jake became mesmerized by the potential of 3D scanning technologies as he discovered that “Smithsonian 3D and Morphosource contain a wealth of social studies possibilities, mnemonic devices, and virtual field trips” (week 6). He even used Autodesk 123D Catch to create a 3D scan of his favorite mini statue from home (week 7; see Figure 3).

Mathematics was the most commonly identified cross-disciplinary content area that participants connected with their own content area. Linda described the application of mathematics and visual spatial abilities in the design of a hexagonal box for an elementary lesson using Silhouette Studio (week four). “Math is all over the place in this software,” reflected Jacob in week seven as he admired the mathematical features embedded in both Silhouette Studio and Tinkercad (a free, web-based app for creating 3D models). Similarly, Michelle, a high school foreign language teacher, expressed an appreciation for the mathematical concepts she discovered and used them to describe her process of designing a foldable yarn bowl using Silhouette Studio (week four). Michelle continued to connect mathematics throughout her reflections as she highlighted the mathematical algorithms she applied to create her crocheted jellyfish with embedded sewable circuits on each tentacle (week eight), “In addition to learning how to crochet in rounds, it also uses math because students need to do the correct number of increases and decreases in order for it to turn out in a properly formed circle” (see Figure 4).

After receiving an enthusiastic response to her mathematical and crocheted jellyfish creation, Michelle presented an impromptu finger knitting lesson to the class in which she described the mathematical patterns involved in knitting an array with rows and columns (see Figure 5).

She later elaborated in her reflection that “these mathematical patterns connect to the linear logic of computer programming or computational thinking and can also connect with the strategic sequencing necessary for expository writing” (week 13).

Identifying non-engineering purposes for maker tools and techniques

Participants admitted an initial struggle with the focus being on engineering at the start of the semester. Jacob noted, “but I’m not an engineering teacher, I’m a social studies teacher. What do I know about engineering?” (week 2). Whether intentionally or unintentionally, participants began to verbalize the desire to find “non-engineering” purposes for the maker tools and techniques while simultaneously using the engineering design process. Weekly reflective journal entries quickly

Figure 4. Michelle's crocheted jellyfish with sewable circuit tentacles.

Figure 5. Michelle explaining the mathematical patterns involved in finger knitting to a classmate.

revealed how participants immediately likened tools to crafting and DIY, such as comparing the Silhouette Cameo machine to the “dusty old die cutter in the teacher workroom” (Tabitha, week two). Similarly, Rachel reflected that “it was cool to learn that the Silhouette was originally made for crafters and scrapbookers, yet it’s based on professional engineering manufacturing tools like laser engravers and large vinyl cutters. That made me reconsider the possibilities” (week two). They noted when they saw related tools throughout their everyday lives, such as seeing 3D printers on science fiction television shows that “totally misrepresent how looooooong [sic] the process takes” (Tammy, week 5) or at inaccessible locations at school causing them to “admir[e] the engineering teacher’s 3D printer from afar” (Michelle, week five).

Once participants had the opportunity to engage with the maker tools and techniques more, they began to highlight their personal creative uses which focused on artistry and personal expression rather than only on the problem-focused engineering challenges. This was clear in Dustin’s use of the Silhouette Studio and Silhouette Cameo to personalize a stencil for his son (week 4), in Maggie’s use of the Inkscape and the laser/engraving machine to create a cardboard portrait of her dog as a gift for her husband (week 14), and in Jett’s 3D hot glue drawing of a happy meal for his son (week 5; see Figure 6).

Figure 6. Jett's 3D hot glue sculpture of a happy meal for his son.

Ultimately, participants began to recognize that this journey was not about finding “non-engineering” connections, rather it was about connecting existing practices with a reconceptualization of how engineering and STEM relate to their lives:

I am a maker. You are a maker. A maker is anyone who makes anything using any medium. Making encompasses any form of creating something. Makerspaces tend to gear towards STEM when in reality they should have all forms of creations and connect to everything. (Michelle, week 6)

Discussion

The purpose of this convergent mixed-methods study was to examine how engaging in this course impacted teachers' familiarity and confidence in teaching the engineering design process. In-depth analysis of teacher participants' pre- to post-test engineering design self-efficacy results indicate that participants experienced an increase in their confidence in engaging in the engineering design process and exhibited a decreased anxiety towards engaging in the engineering design process. Weekly reflective journal entries indicate increase in their familiarity with and confidence in teaching the engineering design process, including describing connections between the engineering design process, making, and curricular connections to maker tools and techniques.

Holistic Picture of Engineering Design Self-Efficacy through Integration of Pre- to Post-Tests and Weekly Reflections

While the quantitative pre- and post-test engineering design self-efficacy instrument provided a snapshot of teacher participants' confidence in the engineering design process at the beginning and end of the semester, the qualitative analysis of the weekly reflective journal entries allowed for a much deeper exploration and explanation for the changes over the 15-week study. Combining these measurements allowed the researchers to compare quantitative and qualitative measurements of participants' belief in their own engineering design capabilities, resulting in a more holistic view of their self-efficacy (Bandura, 1977, 1997) toward engineering design. The evolving familiarity and confidence in teaching the engineering design process included shifts in understanding, acceptance, adaptation, and ownership of changes experienced by the teacher participants. Findings indicated that most participants were able to recontextualize the preconceived values, goals, and meanings of both the engineering design process and maker techniques and tools by acknowledging connections that were relevant to their individualized educational contexts. Though participants began with lower self-efficacy scores in the engineering design process, the weekly qualitative reflections pointed to the possibility that the low base scores were due in part to a lack of familiarity with the process.

Increased Familiarity and Confidence in Teaching Engineering Design Process

When compared with the pre- versus post-test engineering design self-efficacy instrument, the weekly reflective journal entries provided a richer description of how teacher participants' familiarity and confidence in teaching engineering design process changed over the 15-week study. Once participants began experiencing the diverse DBL activities, they reported being able to identify how engineering design process could be integrated into their own unique contexts. This is in line

with the claim made by Hynes et al. (2017) that teachers can only gain confidence through experiencing engineering design for themselves. While the initial pre-test for engineering design self-efficacy indicated a lack of familiarity with concepts within the engineering design process, the teacher participants' weekly reflections acknowledged that the engineering design process is about creative problem-solving—a concept to which all teachers can relate. Their descriptions of familiarity started with the well-known definitions and uses of the engineering design process during their DBL maker activities in the early weeks of the study. Ultimately, toward the end of the study the teacher participants expressed confidence through a flexible interpretation of how engineering and making transcend siloed categories of disciplinary content. The weekly reflective journal entries allowed teacher participants the opportunity to reflect on their experiences with the engineering design process in connection to their personally unique context diversity (i.e., personal background, content area focus, grade level focus, campus culture, teaching strategies, student needs/interests). This reflection contributed to their engagement in cross-disciplinary connections and organically included interconnections between engineering, mathematics, science, and the humanities (i.e., language arts, social studies, visual arts). With this increased confidence, participants began to apply the engineering design process to non-engineering tasks, thus seeing everyday connections to the process. Some participant examples revealed personal creativity, whereas other examples were more explicitly linked to specific uses of processes and tools within a K-12 educational context. Taken together, engaging in both open-ended creative explorations and content-connected activities positively contributed to the participants' increased self-efficacy in engineering design.

The structure of the course examined in this study was set up to allow students to develop stronger connections to how engineering design was already operating in their everyday lives, which demystified engineering design and improved their confidence in their own abilities. The gains in confidence and decreases in anxiety possibly relate to this demystification as they internalized how they (and many others) engage in engineering design regularly, including how other inquiry-based practices (such as the scientific process or instructional design) directly relate to the process of engineering design. Many teacher participants also realized that they did not have to have a college-level technical education in engineering in order to engage in the engineering design process. With this realization, they also felt more comfortable using DBL as a teaching strategy with their own students.

Implications for Teacher Education

This study shows how teachers' engineering design self-efficacy can benefit from longitudinal DBL experiences that are deliberately embedded in teacher preparation coursework. Further, the research team had the opportunity to study the engineering design process as a pedagogy while observing individual and collaborative learning in action. Vossoughi et al. (2016) call for a need to analyze pedagogy in addition to individual, joint, and collaborative learning outcomes because “empirical studies of learning in the context of making tend to foreground individual learning processes rather than joint activity or explicit analysis of teaching” (p. 219). In this study, participants had recurring opportunities to reflect and discuss with classmates as they were actively learning, which allowed them to recontextualize the engineering design process. Beginning by first understanding the purpose and scope of the engineering design process itself, the participants were able to apply it as they designed their own projects within the course and ultimately gained confidence in their ability to teach the process in their own classrooms. Through that experience, they were able to reflect on ways in which other processes they engage in throughout their daily life are similar, thus borrowing the engineering design process and applying it to cross-disciplinary contexts (e.g., scaffolding non-digital tools and digital tools, the writing process, scientific experimentation, instructional design process).

Participants' recurring opportunity to experiment with maker tools and techniques to create personally meaningful artifacts allowed them to recontextualize and appropriate the tools into a K-12 educational context. Beginning first by appreciating the tools in a manufacturing engineering context, the participants were able to use the tools proficiently much like a designer or an engineer would. Additionally, through the act of using the maker tools and techniques, participants were able to discover layers of educational opportunities and connections (e.g., mathematics embedded in software, potential for utilitarian design, virtual field trip explorations).

The intentional DBL structure of the 15-week course included thematic framing of design (2D design, 3D design, and electronics/interactive design), scaffolding of non-digital (crafts, recyclables, scissors, modeling clay, hot glue guns, 3D pens) and digital maker tools (free design software, low-cost hardware, simple electronics components), with a focus on reflective assessment (weekly reflective posts, peer feedback, final autoethnographic video). These course features positively impacted participant self-efficacy in the engineering design process and developed their confidence in integrating DBL with maker tools in a variety of K-12 contexts.

Limitations

The goal of this paper is not to generalize and/or make recommendations, rather to provide a rich, exploratory description of the impact on a group of ten teachers. The small sample size limits extensive quantitative analysis, and the reflection logs include only as much information as each participant chose to share. However, taken as an example case study, this effort is presented as a first step in exploring the ways in which a recurring maker environment experience using DBL can potentially impact pre-/in-service teachers' confidence to integrate engineering through maker activities within diverse educational contexts.

Conclusion

With a growing interest in the integration of maker tools, techniques, and activities to support engineering within educational contexts, it is important to examine ways that teacher education programs can implement best practices to support teachers with these efforts, especially when they have no prior experience with engineering. For this study, convergent mixed methods were used to examine how engaging in this 15-week course impacted teachers' familiarity and confidence in teaching the engineering design process, as viewed through their pre- and post-semester engineering design self-efficacy surveys and their weekly reflective journal entries. These measures are important factors for developing teacher experience and confidence in integrating engineering and DBL strategies within K-12 educational contexts. Quantitative analysis of the pre- to post-test EDSE instrument results indicates that recurring experiences with activities that scaffold interdisciplinary interactions can have a positive impact on teachers' engineering design self-efficacy, including increased confidence in design and decreased anxiety toward design. This finding is triangulated with qualitative findings from weekly reflective journal entries that indicate how participants were able to appropriate and recontextualize the values, goals, and meanings of both (a) the engineering design process and (b) maker tools and techniques within the context of diverse K-12 learning environments. In order to provide a well-rounded experience that uses making to support STEM learning and engineering integration, teacher education programs should include the thoughtful structure of DBL experiences that include (a) purposefully scaffolded themes and tools, (b) recurring opportunity to reflect and discuss with classmates, and (c) iterative experimentation with maker tools and techniques to encourage personally meaningful artifact creation. Developing coursework that can positively impact teachers' *confidence in engaging with engineering* is an important first step to support their *confidence in integrating engineering* and DBL strategies within K-12 educational contexts.

Acknowledgments

Preliminary findings of this research were presented as a brief paper at SITE 2017 Conference in Austin, TX (Smith et al., 2017) and at ASEE 2018 Conference in Salt Lake City, UT (Smith et al., 2018). This material is based upon work supported by the National Science Foundation under grant no. EEC-1531375. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Author Bios

Shaunna F. Smith, Ed.D. is a STEM Specialist at the STEM Pre-Academy (University of Hawaii System). She specializes in professional development for middle school teachers on topics of art, engineering, and STEAM integration. She has experience as a secondary art and digital media teacher and associate professor of educational technology. Contact: shaunna.smith@hawaii.edu

Kimberly Talley, Ph.D., P.E. is a licensed Professional Engineer, an associate professor in the Department of Engineering Technology, and Bobcat Made Makerspace Director at Texas State University. Dr. Talley teaches courses in the Construction Science and Management and Civil Engineering Technology programs, and her research focus is in student engagement and retention in engineering and engineering technology. Contact: talley@txstate.edu

Araceli Ortiz, Ph.D. is Research Associate Professor of Engineering Education in the College of Education at Texas State University and Executive Director of the LBJ Institute for STEM Education and Research. She teaches and conducts research with teachers and students in engineering education as a learning context and instructional strategy. Contact: araceli@txstate.edu

Vedaraman Sriraman, Ph.D. is a Piper Professor and University Distinguished Professor of Engineering Technology at Texas State University. He has served as the Associate Director of the LBJ Institute for STEM Education and Research at

Texas State University. His degrees are in mechanical and industrial engineering. His research interests are in engineering education, sustainability, and applied statistics. Contact: vs04@txstate.edu

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Appendix

Items within each lens of the EDSE (Carberry et al, 2010):

- Conduct engineering design
- Identify a design need
- Research a design need
- Develop design solutions
- Select the best possible design
- Construct a prototype
- Evaluate and test a design
- Communicate a design
- Redesign.