

Teachers' Engineering Design Self-Efficacy Changes Influenced by Boundary Objects and Cross-Disciplinary Interactions

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Work in Progress: Teachers' Engineering Design Self-Efficacy Changes Influenced by Boundary Objects and Cross-Disciplinary Interactions

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Abstract

As part of a larger ongoing NSF-REE-funded project focused on postsecondary maker identity within a university makerspace context, this paper reports on ten in-/pre-service teachers' engineering design self-efficacy changes after participating in a semester-long makerspace experience at a large Hispanic-serving university in the Southwestern United States. The aim of this part of the project is to discover specific learning models that involve both STEM university students and in-/pre-service teachers in order to develop teamwork, self-efficacy, communication, and identity formation in the maker environment. The theoretical lens of boundary objects (Star & Griesemer, 1989) and cross-disciplinary collaboration (Gorman, 2010) are used to examine how specific learning models can influence change in engineering design self-efficacy. This paper presents the details of the procedural context and learning models integrated within a graduate-level educational technology course, reports on the pre-/post-test results from the Engineering Design Self-Efficacy survey instrument, and discusses implications for engineering education and engaging teachers in authentic maker integration within K-12 educational contexts.

Introduction

Though currently very popular in pop culture and education, there are many tensions within the burgeoning maker movement as individuals seek to define it through disparate representations and recognitions of what “making” matters (Buechley, 2013; Vossoughi, Hooper, & Escudé, 2016). Blikstein (2013), Martin (2015) and Vossoughi, Hooper, and Escudé (2016) note that there are many potential positive contributions the maker movement has to offer education and society at large; however, when it comes to educational contexts they warn us that merely giving technology to a student is not a meaningful integration effort. In order to make the most of integrating making within K-12 educational contexts, we must simultaneously examine the teaching methods and the types of learning that result. Buechley (2013) and Martin (2015) also note that diverse representations of maker techniques and tools need to be presented and explored in authentic ways in order to make an equitable impact, including non-digital crafting techniques (sewing, knitting, textiles, crafting kits) in addition to the popular digital technologies (free design software, digital fabrication technologies, visual-based computer programming) that frequent current discussions about maker integration. Similarly, Vossoughi, Hooper, and Escudé (2016) suggest a framework for “equity-oriented research and design: critical analyses of educational injustice; historicized approaches to making as cross-cultural activity; explicit attention to pedagogical philosophies and practices; and ongoing inquiry into the sociopolitical values and purposes of making” (p. 206). In addition to this equity-oriented approach, the authors use the theoretical lens of boundary objects (Star & Griesemer, 1989) and cross-

disciplinary collaboration (Gorman, 2010) to examine how specific learning models within a recurring maker education experience can impact in-/pre-service teachers' engineering design self-efficacy. This paper presents theoretical literature, details the procedural context and learning models integrated within the graduate-level educational technology course, reports the pre-/post-test results from the Engineering Design Self-Efficacy survey instrument, and discusses implications for engineering education and engaging teachers in authentic maker integration within K-12 educational contexts.

Background

Boundary Objects

The theory of boundary objects is important when considering a novice's need to gain confidence with new and somewhat unfamiliar tools and/or their instructional uses and applications. Star & Griesemer (1989) originally defined boundary objects as "those scientific objects which both inhabit several intersecting social worlds ...and satisfy the informational needs of each of them. Boundary objects are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (p. 393). Similarly Bowker, Timmermans, Clarke and Balka (2016) further define boundary objects as "representational forms—things or theories—that can be shared between different communities, with each holding its own understanding of the representation" (p. 52). Essentially, boundary objects are phenomena (i.e., information or knowledge) represented and/or understood in different ways by different participants (i.e., participants who have varied experiences, varied perspectives, and associate the objects with varied meanings). It is through this lens that we look at how processes (e.g., engineering design process) and tools (e.g., non-digital craft materials, digital technologies) serve as boundary objects as in-/pre-service teacher participants delve into the learning potential of a hands-on maker environment.

Cross-Disciplinary Collaboration

Similarly, cross-disciplinary collaboration is important when considering a novice's need to learn from one another through peer-to-peer interactions and/or others who are experienced. This is especially important for helping novices to gain confidence in the engineering design process. Gorman (2010) points out the importance of cross-disciplinary collaboration by stating that,

[it] increasingly characterizes today's science and engineering research. The problems and opportunities facing society do not come neatly sorted by discipline. Difficulties arise when researchers from disciplines as different as engineering and the humanities work together and find that they speak largely different languages. (p. 12)

This is of critical importance for teacher educators in the STEM field as we (teacher educators) are tasked with not only building in-/pre-service teacher self-efficacy with new instructional strategies, but also tasked with bridging disciplines and negotiating the boundaries between exploratory "fun" activities and the acquisition of knowledge and skills that can propel students successfully into the STEM pipeline.

In the context of this research, maker technologies and tools were presented as boundary objects (Star & Griesemer, 1989) that could be understood as shared objects between the technical engineering context and the design-based learning approaches within K-12 educational contexts. Similarly, the engineering design process was explored and recontextualized to allow in-/pre-

service teacher participants opportunity to explore and make connections to other iterative processes that are used in everyday K-12 teaching and learning scenarios (e.g., the writing process, scientific experimentation, instructional design process). The encouragement of cross-disciplinary collaboration (Gorman, 2010), was strategically leveraged to allow time for participants to learn from one another's diversity in the classroom makerspace (i.e., personal background, content area focus, grade level focus) as well as engage in peer-to-peer learning through interactions and discussion with non-education majors in the collaborative university makerspace. Previous qualitative findings from a semester-long study in an educational makerspace indicated that cross-disciplinary collaboration was an important factor for in-/pre-service teacher participants to appropriate and recontextualize the value, goals, and meanings of both the engineering design process and maker technologies and tools within the context of diverse K-12 learning environments (Smith, Talley, Ortiz, & Sriraman, 2017).

Methodology

As part of a larger ongoing NSF-REE-funded project focused on postsecondary maker identity within a university makerspace context, this paper reports on ten in-/pre-service teachers' engineering design self-efficacy changes after participating in a semester-long makerspace experience at a large Hispanic-serving university in the Southwestern United States. The aim of this part of the project is to discover specific learning models that involve both STEM university students and in-/pre-service teachers in order to develop teamwork, self-efficacy, communication, and identity formation in the maker environment. As such the following research question guided the study: What is the impact of a semester-long cross-disciplinary makerspace experience on in-/pre-service teachers' *engineering design self-efficacy*?

Participants

Participants included ten graduate M.Ed. students (5 females and 5 males; 7 in-service and 3 pre-service seeking initial certification) who were enrolled in a graduate-level educational technology course during the Fall 2016 semester at a large Hispanic-serving institution in the Southwestern United States. The course focused on integrating maker technologies and tools into educational contexts and met face-to-face for 15 weeks (45 contact hours). Participants were not required to take the course, rather they chose to take it as an elective to accompany their educational technology program courses. They were not required to participate in the research portion of the course; however, all ten participants did sign IRB-approved consent forms to indicate their willingness to participate.

Data Collection and Analysis

Pre-/Post-test administration of the Engineering Design Self-Efficacy (EDSE) survey instrument (Carberry, Lee, & Ohland, 2010) serves as the primary data set. The EDSE was chosen for this study because it is a validated instrument for measuring task-specific self-concepts, which Carberry, Lee, and Ohland (2010) state are "any variable concerning the understanding an individual has of him or herself for a given task. Understanding of self is what leads to the desire, or lack thereof, to perform a given task" (p. 71). The 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. It was administered at the beginning of the first class meeting and at the end of the final class meeting. Using Pearson Correlation, the

Engineering Design score (ED) and Engineering Design Process score (EDP) scores were compared for their correlation in each lens for both the pre- and post-tests and, after finding a correlation between these scores, the ED was then used for additional analysis (Carberry et al, 2010). The pretest and posttest ED scores for each lens of the EDSE were compared with a one-tailed, paired t-test to assess statistical significance of the change between the pretest and posttest results. Paired t-tests were selected to specifically measure the changes in students who completed both the pretest and posttest ($n = 7$). 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 changes that resulted from this project.

Context, Course Procedures, and Learning Models

The semester-long graduate-level educational technology course took place as a part of the Department of Curriculum & Instruction in the College of Education and was designed and taught by the first author. The course was developed with the intention to help in-/pre-service education majors from a variety of personal backgrounds, content area foci, and grade level foci, this course was based on theoretical recommendations from Vossoughi, Hooper, and Escudé's (2016) equity-oriented research and design for integrating making, which include the following attempts to address their recommendations, 1) specific introduction of free and/or low cost maker technologies and tools 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 content standards and connections, personally meaningful creation and expression, and creative experimentation and problem-solving.

The course focused on the integration of makerspace themes into a variety of K-12 educational settings and included scaffolded activities covering non-digital and digital techniques for the following topics: subtractive manufacturing, textiles, additive manufacturing, and simple electronics. The majority of the activities took place in the classroom makerspace, which is a classroom lab in the College of Education specifically designed to enable education majors to explore design-based technologies and maker techniques that can be integrated into K-12 educational contexts (see Figure 1).



Figure 1. *Classroom makerspace in College of Education*

Participants also had open access to the collaborative university makerspace that had larger equipment (e.g., laser engraving machine, digital embroidery machine, sewing machines, large format 3D printers, and 3D CNC milling machine), which was facilitated by student volunteers who were non-education majors (see Figure 2).



Figure 2. *Collaborative university make space provides open access to all university students.*

Week 1: Makerspaces Intersections of Art and Everything provided an overview of the course and a visit to the collaborative university makerspace. This set the stage for introducing the thematic units and the assignments for the course, which included 1) scaffolded non-digital and digital techniques during hands-on activities each class, 2) weekly reflective journal entries, 3) thematic “choose your own exploration” projects including the development of a standards-based lesson for K-12 educational context and an exemplary artifact, 4) a service learning project in the local community, and 5) a culminating reflective video documenting their creative evolution as an individual and a practitioner.

2D Explorations. The second week launched the 2D explorations unit, which encouraged participants to work with a variety of tools (i.e., vector-based design software including Silhouette Studio, Inkscape, and Adobe Illustrator, Silhouette Cameo paper/vinyl cutting machines, laser engraving machines, sewing machines, embroidery machines) and 2D materials (i.e., paper, vinyl, cardboard, acrylic, and textiles). Specific activities in the 2D explorations unit included:

- Week 2: Kirigami Techniques: Artful Cultural Studies Across Place & Time
- Week 3: Modular Paper Engineering: Pop-ups, Sliceforms, Slidetogethers, & Shape Nets
- Week 4: Textiles: Sewing, Embroidery, Knitting, & Printmaking
- Week 5: Choose Your Own 2D Exploration, Gallery Walk Presentation & Discussion

Figure 3 shows the equipment available in the classroom for 2D explorations. Additional equipment is stored in a nearby cabinet and is available for use on work tables in the center of the room. Resource books are arranged on a nearby shelf to help promote self-help. Laser engraving machine is housed in the collaborative university makerspace and was available to students during class time and open lab hours.

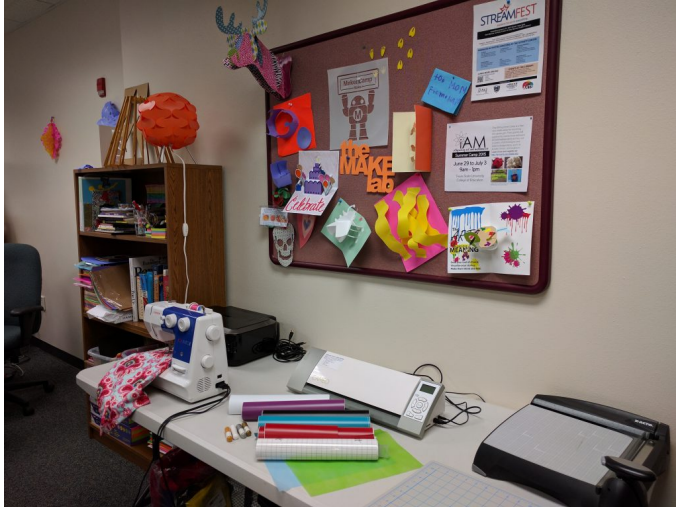


Figure 3. Classroom access to sewing machine, paper/vinyl cutting machines, additional 2D crafting equipment, and student examples.

3D Explorations. The 3D explorations unit encouraged participants to explore additive manufacturing including a variety of 3D CAD modeling software (i.e., Tinkercad, Blender, Autodesk Education Initiative free access software, Makerbot PrintShop), 3D drawing tools (i.e., hot glue guns, 3D pens with PLA filament), and 3D printers (MakerBot Replicator Mini, MakerBot Replicator). Participants were introduced to the Nomad CNC milling machine in the collaborative university makerspace through a demo; however, they were not required to create projects with it. Specific activities in the 3D explorations unit included:

- Week 6: 3D Printing: 3D CAD Modeling, Ethics, & Replicability
- Week 7: Wearable Forms: 3D Pendants, Rings, Bracelets, & Modular Pieces
- Week 8: 3D Scanning: The Case of the Missing Piece
- Week 9: Choose Your Own 3D Exploration, Gallery Walk Presentation & Discussion

Set up in a similar manner to the 2D area, this area focuses on tools that work with 3D materials, including modeling clay, blocks, and 3D printing. Participants use the work tables in the center of the room to create their 3D models using their own devices with free CAD software (e.g., Blender, Tinkercad, Makerbot Print Shop). When they are ready to 3D print, they load their .STL file onto one of the designated laptops that operate the 3D printers (via USB drive or through transferring from cloud-based storage) and print directly to the 3D printer. A nearby cabinet contains additional modeling tools and additional 3D printer filament options (always stored in plastic storage bags to limit warping damage to the filament). A nearby shelf contains student-created examples and resource books to help promote self-help. Four additional large MakerBot Replicator 3D printers are accessible in the collaborative makerspace and were available to students during class time and open lab hours. Figure 4 shows classroom equipment and resources.



Figure 4. (L) Classroom access to Makerbot Replicator Mini 3D Printers and (R) student examples.

Simple Electronics Explorations. This unit included a variety of equipment and resources focused on simple electronics and computer programming that are easy to access for beginners. Through our grant funding, we are fortunate to have class sets of electronics kits that allow us to scaffold beginner activities, including LittleBits, SnapCircuits, Makey Makeys, and Picoboard. Specific activities in the simple electronics unit included:

- Week 10: Input + Output: Making Things “Happen” with Inexpensive LEDs & Motors
- Week 11: Paper Circuits: Conductive Tape, Conductive Paint, Inputs, & Sensors
- Week 12: Sewable Circuits: Conductive Thread, Sensors, & Textile Techniques
- Week 13: Interactive: Computational Thinking, Scratch, & Micro-controllers
- Week 14: Choose Your Own Electronics Exploration, Gallery Walk Presentation & Discussion

A nearby cabinet contains additional electrical components organized in plastic boxes, including batteries (AA, AAA, CR2032), conductive materials (steel thread, copper tape, aluminum tape, paper clips, alligator clips), LED lights (diodes with resistor legs), motors (DC motors, pager motors), and additional craft materials. All equipment was available for participants to check out and take home for further explorations, including the electronics kits listed above. Student-created examples are on display throughout the area to help inspire new projects. Resource books are arranged by topic on a nearby shelf to help promote self-help and just-in-time learning (See figure 5).



Figure 5. *Classroom access to electronics components, computer programming kits, resource books, and student examples.*

Finals. The culminating activities in the course included service learning projects and maker fest show and tell presentations. A service learning project involved participants facilitating maker activities at a local community event and then writing a reflection, which consists of a 500-word description of the activities they facilitated, how they engaged with the participants, what they learned from the experiences, and elaborate if there was an impact on their own creativity, design process, knowledge of tools and techniques, and/or confidence in the ability to teach others. Though this assignment was introduced early in the semester to allow for participants to schedule accordingly, it was specifically addressed during Week 15 so that participants could finalize their preparations for the event:

- Week 15: Facilitate Activity at Public Library (Service Learning Event)

Lastly, the reflective video project/final “exam” served as a culminating project that allowed each participant to explore their own creative evolution throughout the course, which was graded based on a rubric designed by the first author (Smith, 2017). Participants created a (<10 minute) reflective video that documented their semester-long experience in this course, including design processes engaged in, artifacts created, and implications for future practice. This was an autoethnography that focused on the participant’s uniquely individualized experiences, creations, and images (not the generic experiences, creations, or images of others). Much like the service learning project, this final project was introduced early in the semester and participants were encouraged to curate images and videos from their weekly reflective journal entries to be used as source material for their final reflective video. Participants presented this reflective video at the final class meeting as part of a larger University Maker Fest Show and Tell Event:

- Week 16 (Finals Week): Present at University Maker Fest Show & Tell Event

Results of Engineering Design Self-Efficacy Instrument

Pearson Correlations were used to compare the Engineering Design score (ED) and Engineering Design Process score (EDP) in each of the four lenses of the Engineering Design Self-Efficacy instrument (EDSE) (Carberry et al., 2010). The correlations were higher for the post- tests than for the pre-tests (see Table 1 below). The authors hypothesized as the in-/pre-service teachers

better understood the engineering design process at the end of the course that they were then able to be more accurate in self-reporting.

Table 1: Pearson Correlation Between In-/Pre-Service Teachers' Engineering Design (ED) & Engineering Design Process (EDP)

	Confidence	Motivation	Success	Anxiety
Pre-test	.62	.94	.91	.73
Post-test	.84	.99	.94	.97

One-tailed, paired t-tests were used to compare the pre-tests and post-tests for each lens. Two lenses showed statistical significance in their change over the semester: Confidence and Anxiety. The In-/Pre-Service teacher participants in this study had a statistically significant increase in their confidence and a statistically significant decrease in their anxiety to conduct engineering design (see Table 2 and Figure 6 below).

Table 2: Pre- and Post-test Statistics and Paired t-tests Results of In-/Pre-Service Teacher Engineering Design Self-Efficacy

	<i>Pre-test</i>		<i>Post-test</i>		<i>t</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Confidence	37.14	28.70	71.43	15.74	2.88	.014*
Motivation	70.00	20.00	72.86	22.15	0.22	.418
Success	60.00	16.33	71.43	22.68	1.62	.078
Anxiety	70.00	29.44	37.14	24.30	-2.76	.016*

*Statistical significance at the .05 level.

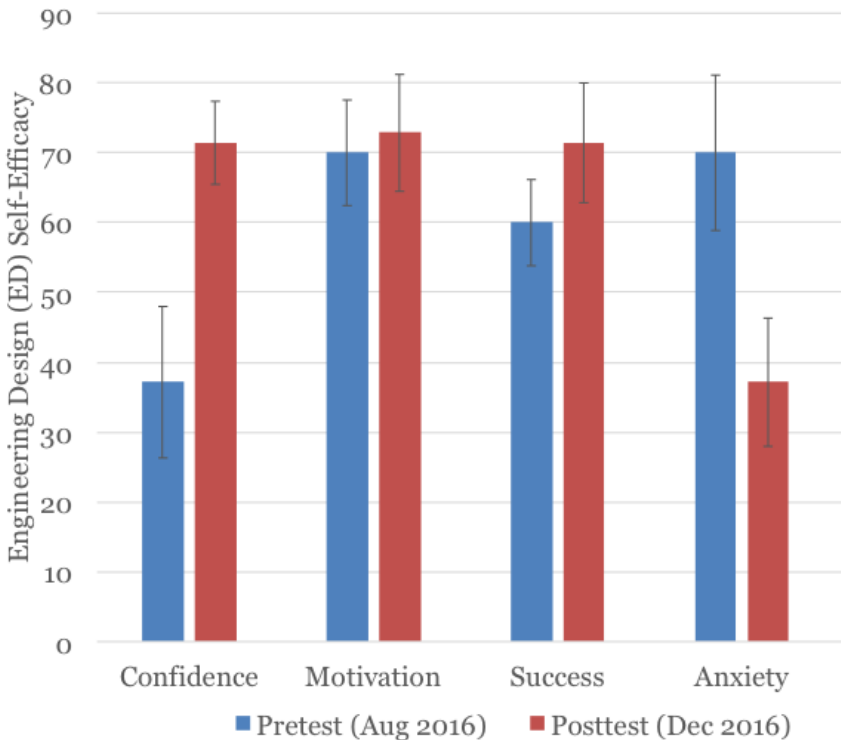


Figure 6. Pre-test and post-test results of in-/pre-service teachers' Engineering Design Self-Efficacy.

Discussion

Implications for K-12 Teaching and Teacher Education

The quantitative results above show that participants experienced increased confidence in engineering design and decreased anxiety about engineering design. The recurring opportunity to experiment with maker technologies and tools in order to create personally relevant artifacts allowed participants to gain confidence with the tools and see them as boundary objects that had a clear place both in the world of engineering design manufacturing and within their own K-12 educational context (Smith, Talley, Ortiz, & Sriraman, 2017). For example, using the paper/vinyl cutting machine allowed participants to connect prior knowledge of non-digital die-cutting machines and paper crafting techniques to newly developed knowledge of subtractive manufacturing techniques used to design artifacts out of paper, vinyl, cardboard, acrylic, and wood. Due to the scaffolded structure of the course, the participants began making stronger connections to how engineering design was already operating in their everyday lives, which demystified the engineering design process and improved their confidence in their own abilities. The gains in engineering design confidence and decreases in engineering design anxiety probably relate to this demystification as they internalized how they (and many others) engage in engineering design regularly, but without being aware of how their practices (such as the scientific process) directly relate to the process of engineering design. In the end, they realized that they didn't have to use all of the technical formulas of engineering in order to engage in the engineering design process. Experiencing a course that uses learning models described in this paper can positively influence in-/pre-service teachers' confidence with the engineering design

process and potentially help motivate them to implement similar activities that infuse engineering design within their own K-12 content area context.

Implications for Engineering Education

There are implications for engineering education even though this research is in the context of a graduate-level educational technology course for in-/pre-service teachers. Similar learning models and activity sequences that scaffold non-digital and digital techniques could be applicable for teaching engineering design to a diverse audience (i.e., freshman design, introduction to engineering, etc.). The breadth of diverse prototyping experiences could allow for the integration of culturally relevant pedagogy and draw upon participants' prior experiences. Also, integration of these types of learning models early within an engineering program could lead to greater design experimentation throughout students' future engineering courses and/or inspire more innovative senior design projects at the culmination of their engineering program.

Next Phase of Research

New work is currently being conducted, which applies these same theories to examine the maker identity transformations of faculty from the College of Education and the College of Science and Engineering who engage in recurring cross-disciplinary interactions within a university makerspace professional development series. Using a condensed version of the scaffolded course structure, each thematic unit has been compressed into three one-day professional development sessions. These sessions include non-digital techniques and digital technologies and tools to guide faculty participants through hands-on explorations and discussion about related pedagogy. Faculty participants are then charged with creating and implementing their own maker lesson with their university students, which includes administering a pre-/post-test, collecting completed artifacts (i.e., still images and/or video clips), and inviting students to participate in focus group interviews with the research team. Preliminary results include 26 faculty participants who teach in a variety of departments and program areas across the university, including chemistry, curriculum and instruction, early childhood education, engineering, mathematics education, psychology, science education, social education, and talent development.

Conclusion

This paper reports the positive impact of a 15-week educational technology course focused on integrating maker technologies and tools into educational contexts on ten in-/pre-service teacher's engineering design self-efficacy. Details of the procedural context and learning models integrated within the graduate-level educational technology course are provided, including weekly outlines of thematic units, scaffolded hands-on activities, and formative and summative assessment strategies (i.e., weekly reflections, service-learning projects, reflective video projects). Quantitative analysis of the pre-/post-test results from the Engineering Design Self-Efficacy (EDSE) survey instrument indicate statistically significant changes on the participants' confidence in engaging in engineering design and statistically significant reduction on participants' anxiety. These findings are important because increased confidence and reduction in anxiety are integral steps toward empowering pre-/in-service teachers to authentically integrate engineering concepts within their K-12 curricula. Implications for engaging teachers in authentic maker integration within K-12 educational contexts as well as implications for how

these learning models could support engineering education at a post-secondary level are provided.

Acknowledgements

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.

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