STEL Practice and the Integration of Tinkering and Take Apart in the Elementary Classroom

By Leah R. Cheek, Vinson Carter, and Michael K. Daugherty

ABSTRACT

Over the past two decades the Standards for Technological Literacy (STL) (ITEEA, 2000) have challenged educators to search for strategies to implement and address improvements in technological literacy rates among P-12 students. Capobianco, Yu, and French (2014) acknowledged "the integration of engineering practices in the science classroom as early as grade one shows potential in fostering and sustaining student interest, participation, and self-concept in engineering and science" (p. 275). The updated Standards for Technological and Engineering Literacy (STEL) (ITEEA, 2020) are organized into three STEL structural branches that combine to create a pedagogical and domain knowledge configuration for technology and engineering teachers (ITEEA, 2020). Although the three STEL organizational branches are at the forefront, this study attempts to focus on and identify the relationship between the practices surrounding the eight core STEL standards: *systems thinking, creativity, making and doing, critical thinking, optimism, collaboration, communication, and attention to ethics*. These specific practices are designed for the integration of STEM in the classroom and may be advantageous toward promoting technological and engineering literacy through tinkering and take-apart teaching methodologies. Acknowledging that the teacher may be the STEM integration decision maker in the classroom, this study attempts to discern the link between STEL, tinkering and take-apart teaching methodologies, and pre-service elementary teacher candidates' self-efficacy in the STEM disciplines of technology and engineering education as well as providing implications for future practice in the elementary classroom.

Keywords: Integrated STEM Education, Elementary Education, Standards for Technological and Engineering Literacy (STEL), Tinkering

INTRODUCTION

Propelled by the prediction of future shortages in the workforce in science, technology, engineering, and mathematics (U.S. Bureau of Labor Statistics, 2021) politicians, researchers and educators continue to focus on enhancing STEM experiences and proficiencies for P-12 students. According to the National Science Foundation (2018), U.S. policymakers have emphasized the need for a substantial rise in the number and diversity of students pursuing degrees and careers in STEM fields. This emphasis is motivated by the goal of improving innovation and maintaining global competitiveness. Contrary to the ongoing efforts to increase student interest in STEM fields, American students are entering STEM-related pathways at a lower rate each year (National Science Foundation, 2018). Archer, Moote, MacLeod, Francis, and DeWitt (2020) stated:

> Increasing and diversifying participation in STEM is a pressing concern for policymakers, practitioners and researchers across the globe. Moreover, despite longstanding investments of time and resource in attracting more young people, patterns in STEM participation in post-compulsory schooling remain[s] stubbornly resistant to change. (p. 4)

Coupled with the prediction of a future workforce shortage in STEM fields, Archer, et. al. (2020) noted that by age ten some young people view STEM fields as being beyond their abilities and remove themselves from STEM-related endeavors due to lack of confidence. Daugherty and Carter (2018) further illustrated this phenomenon and the need for early experiences with STEM detailing:

> By the time students reach 4th grade, 30% have lost interest in science. By 8th grade, almost 50% have lost interest or deemed it irrelevant to their future. This means that millions of students are tuning out or lack the confidence needed to pursue a future in STEM fields. (p. 9)

Manifold reflections like those of Cook and Bush (2018) echo the awareness students need to be prepared for jobs that do not yet exist. Students may need to be creative problem-solvers and critical thinkers to circumnavigate the unknown future job market. Waiting until students are in junior high or high school to include STEM integration may be too late, making it imperative for educators to include research and strategies designed to improve the delivery of standards through project-based learning, technological literacy, innovation and design, or related information in the STEM fields beginning in early elementary or primary grades.

STEM Integration in the Elementary Classroom

Swift, Strimel, Bartholomew, & Yoshikawa (2018) affirm, “a weak emphasis on innovation and design in education, especially at the primary level, has contributed to challenges in meeting the STEM-related job demands” (p. 7). Supporting this assertion, Putri, Sumiati, and Larasati (2019) accentuate that reality and clarify that the societal purposes of education are constantly changing, and in turn, curriculum and teaching strategies must also be transformed. Meanwhile, Brophy, Klein, Portsmore, and Rogers (2008) underscore the importance of “preparing teachers to blend engineering education into the curriculum requires identifying and understanding better the unique interaction of pedagogical knowledge, domain knowledge, and the combination of the two” (p. 381). By providing elementary students with engaging, encouraging, and effective experiences, these young students may have a greater chance to increase their self-efficacy in the STEM disciplines. In response to this direction, the International Technology and Engineering Educators Association (ITEEA) has developed the Standards for Technological and Engineering Literacy, or STEL (ITEEA, 2020a), updating their previous Standards for Technological Literacy (ITEAA, 2000b). These new standards serve as a resource for educators to identify how STEM constructs might align with lessons and the integration of curricula with other disciplines (Daugherty, Carter, & Sumner, 2021).

Standards for Technological and Engineering Literacy (STEL)

Core disciplinary standards, technological and engineering practices, and technological and engineering contexts are the three STEL technological and engineering organizers that combine to create a pedagogical and domain knowledge framework for technology and engineering teachers (ITEEA, 2020a). Robinson (2017) points to an irony when comparing the call to action for a STEM workforce and the current reality in the classroom by asserting, “…although engineering has the power to integrate STEM disciplines for young children, engineering does not appear as a subject area in the accountability examinations; therefore, some schools have been slow to find space in the elementary curriculum to accommodate it” (p. 20). Strimel, et. al. (2017) contend the intersubjective challenge of communicating the role of technology education in P-12 has long troubled teachers. As noted by Bartholomew, Strimel, Zhang, and Homan (2018) STEM education has become increasingly important at the elementary school level with outcomes focused on learning, motivation, and 21st-century skills. Fortunately, many elementary classrooms have the structural fluidity that may provide opportunities for meaningful curriculum integration (Carter, Kindall & Elsass, 2016). Miller (2021) explains, “Providing early access to STEM opportunities can take many forms from formal educational opportunities to informal [ones] and does not require expensive equipment” (p. 2). Auspiciously, all three technological and engineering organizers of STEL may serve as a guide for teachers and students to understand and identify the relationships between technology and engineering and other real-world situations and challenges. Tinkering and take-apart methodologies may provide a path for teachers to approach STEM opportunities while connecting students to STEL practice.

Tinkering and Take Apart to Facilitate Integration in Elementary Classrooms

Comprehending how something works and applying that knowledge in a novel way depends on opportunities to tinker, take apart, explore and create; things that define the foundation of learning engineering (Brophy, et. al, 2008). Although educators have acknowledged the value of incorporating tinkering challenges in STEM education, elementary teachers may lack the self-efficacy to integrate tinkering and take apart as an engineering process in their own classrooms. Take apart is a process also known as deconstruction in which students use real tools such as a screwdriver and pliers to take apart an item/device in order to gain insight into how things work and the components required to make the item/device operate (Heroman, 2017). Furthermore, Resnick and Rosenbaum (2013) declared:

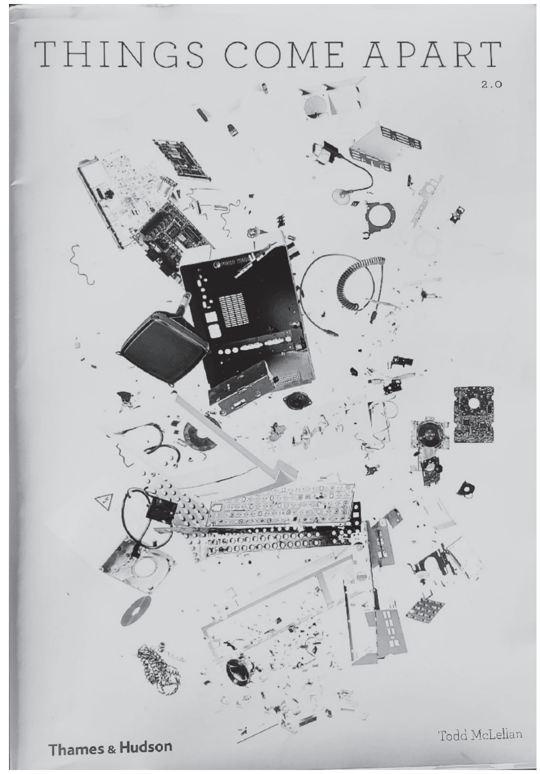
> The tinkering approach is characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities. Tinkering is undervalued (and even discouraged) in many educational settings today, but it is well aligned with…the goals of the progressive-constructionist tradition (p. 164).

Although not a great deal of research has been conducted on tinkering, particularly in the elementary and pre-service teacher classroom, this attitude may encourage educators to reassess their goals, explore new paths, and imagine new possibilities. Moreover, Plano, Clark, and Ivankova (2016) asserted that personal and professional experiences and expertise impact educators.

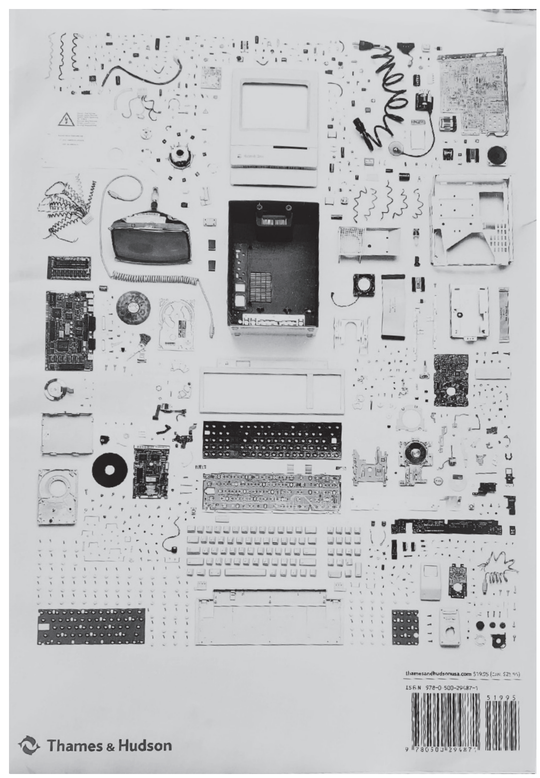
Consider the following scenario and the potential impact on educational research:

> Mrs. Doster has had a long career as a public-school elementary teacher, and these experiences have shaped who she is as a teacher and undoubtably influence her action-research and classroom practices. She often thinks specifically about a student who was in her third-grade classroom named Tori. Tori was the tallest in the class with a big toothy smile and an enormous pink bow. Tori loved school, but mostly because she was good at "right" answers, which had earned her straight A's. Tori knew how to take a test. She could memorize and regurgitate answers with the best, but Mrs. Doster sensed in Tori the ability to be a thinker and an innovator. She believed Tori deserved more. Mrs. Doster would picture twenty-two-year-old Tori ill-prepared for her first job interview as she was asked what would make her the best candidate for a job. How would she reply? Tori might respond by saying, "Tests. I can take tests. I color inside the lines. I think inside the box. Tell me what to think and I'll think it."

> As a society, we learn about the world and advance our understanding through science, technology, engineering, and mathematics practices and experiences (Kelley & Knowles, 2016). Since the increase of global awareness to expand STEM education, today's learners need to be ready to know how to collaborate, communicate, think critically, and create to be prepared for our changing world and the changing prediction of future shortages in the workforce in science, technology, engineering, and mathematics. Moye (2019) declared that preparing technological and engineering literate students should not be left to chance and should include hands-on, real-world experience in students' classrooms. Recognizing Daugherty and Carter's (2018) conclusions about early decisions and self-efficacy in STEM disciplines, many educators might also be concerned about Tori and other students like her and wonder if third grade was indeed too late. Perhaps tinkering and take-apart teaching methodologies might be the answer to the question posed by Tori and her teacher—as well as all elementary students.



Front Cover



Back Cover

Figure 1.
Images from McLellan's Things Come Apart

INTRODUCTION OF MCLELLAN'S (2013) GUIDE TO DECONSTRUCTING *Things Come Apart: A Teardown Manual for Modern Living*

Inspired by the publication of McLellan's (2013) guide to deconstructing, *Things Come Apart: A Teardown Manual for Modern Living*, a potential model for the integration of STEL practice will be addressed. This model is aligned with the elementary level and focused on technological and engineering contexts. McLellan, a photographer, systematically demonstrates the complexity and precision of the inner workings of mechanical and electronic objects and presents the dismantled objects in a meticulous arrangement format underscoring the complexity and design of each item. The images represent that even the most intricate and seemingly complicated technological item can be broken down, analyzed part by part, and understood. Each photograph offers a chance for a new vision and interpretation of the way things work, which may ultimately lead to the connection that these parts could be combined with other parts to create something new.

APPLICATIONS GUIDED BY THE SECOND ORGANIZER OF STEL PRACTICES, TECHNOLOGICAL AND ENGINEERING CONTEXTS

When analyzing the eight core standards, the STEL practices *systems thinking, creativity, making and doing, critical thinking, optimism, collaboration, communication* and *attention to ethics* are connected to the photographs in *Things Come Apart*. The images inside the book include exploded views of items ranging from a transistor radio, mechanical pencil, a combination lock to a fire extinguisher, a sewing machine, and a telescope. The STEL practices have the potential to work in tandem with the images in Things Come Apart to set guideposts for tinkering and the integration of take-apart methodologies into the elementary classroom. For example, *systems thinking*, "refers to a holistic understanding that all technologies are composed of interconnected parts" (ITEEA, 2020b, p. 14). McLellan's photographs in *Things Come Apart* unambiguously demonstrate this idea (see Figure 1.).

An analysis of McLellan's photographs also highlights the STEL practice of *creativity*, which is defined as "the use of investigation, imagination, innovative thinking, and physical skills to accomplish goals" (ITEEA, 2020b, p. 15). McLellan's images may inspire teachers to provide students with the opportunity to do the 'taking apart' and to take their own photographs of deconstructed items. Concepts related to the STEL practice of *making and doing* may follow, since they are the factors that differentiate technology and engineering from other fields (ITEEA, 2020b, p. 15). The teacher may contemplate that the students could not only take something apart, but after making the discovery of what is inside, the students might repurpose these cannibalized parts into something new by *making and doing*. This may lead to the next step in this thought-experiment by drawing connections to the STEL practice of *critical thinking* that would be required to repurpose found items. "Critical thinking involves logical thinking, reasoning and questioning in the process of making informed decisions" (ITEEA, 2020b, p. 15).

When students discover how things work from a rudimentary perspective and possess a belief that the technology could be improved, they may be experiencing the practice of STEL *optimism* (ITEEA, 2020b, p. 15). Next, collaboration refers to "having the perspectives, willingness, and capabilities to work as part of a team" coupled with *communication*, which in this case could appear as McLellan inspired photographs employed to share with others what has been discovered through take-apart activities. Finally, *attention to ethics* could focus on "the impact of technological products, systems, and processes on others and the environment" (ITEEA, 2020b, p. 15). Through the lens of the student-centered STEL practice, *Things Come Apart* may provide a roadmap for teachers to guide students to encounter the big ideas central to understanding more about technological and engineering practices.

Conversely, the teachers leading the take-apart lesson would most likely need to possess a positive self-efficacy about their abilities to teach technology and engineering education in the elementary classroom before even agreeing to facilitate a take-apart experience. One concern is that it is generally agreed upon is that many elementary teachers may not have confidence in their ability to teach technology and engineering (Cunningham, 2009; Hsu, Purzer, & Cardella, 2011; Novak & Wisdom, 2018). Bandura (1977) described self-efficacy as the "conviction that one can successfully execute the behavior required to produce outcomes" and explains the "procedures, whatever their form, serve as means of creating and strengthening expectations of personal efficacy" (p. 193). Also relaying the importance of teacher self-efficacy, Brophy and Mann (2008) continue by stating teachers need ample understanding and personal experiences with engineering to confidently integrate engineering in the classroom. Miller (2021) recalled her own doubts due to lack of experience when asked about technology and engineering as an undergraduate. She identified the "sentiment of fear, feeling inadequate, and not smart enough" (p. 1).

Tinkering and Take Apart as a Link to STEL Integration and Practice

Considering the work of Bandura, Brophy and Mann, and Miller, the researchers designed a pilot study for pre-service teacher candidates in an introductory STEM education course to examine the tinkering and take-apart self-efficacy of pre-service teacher candidates and their confidence in utilizing tinkering and take-apart activities in their future classrooms. A pilot study was chosen because, "the purpose of conducting a pilot study is to examine the feasibility of an approach that is intended to be used in a larger scale study" (Leon, Davis, & Kraemer, 2010, p. 626). Two sections of *Introduction to STEM Education* at a large southern university were selected. This course was designed to provide a meaningful look at integrated STEM teaching methods, curriculum development, and the expansion of the skills and dispositions necessary to prepare teachers to develop an integrated STEM curriculum and teaching wherewithal for K-6 classrooms. In addition, this course is taken by all elementary teacher education candidates during their junior or senior year in the elementary teacher education program, immediately before their student teaching internship begins.

METHODOLOGY AND PROCEDURES

The purpose of this research was to examine both the tinkering and take-apart self-efficacy of pre-service teacher candidates and their confidence in utilizing tinkering and take-apart activities in their

Table 1. Tinkering and Take-apart Survey Question Statement

1. I am generally confident taking things apart to see how they work.
2. I typically have a good understanding of how something works by looking at it.
3. I often tinker with things around me and use that ability to create new things.
4. I often try some things that I don't already know how to do.
5. I generally understand how parts work together to make the whole operate.
6. I basically understand the connection between tinkering and learning in the classroom.
7. I basically understand the connection between tinkering and learning.
8. I have a general sense of how things work.
9. I have a general understanding of what it means to "tinker."
10. I understand things more clearly when I can construct tangible objects.
11. Previously, I have removed parts from one item and used those parts in another way.
12. More often than not, I try to understand how things work to better solve problems.
13. I can tinker to help me demonstrate what I know or what I have learned.
14. Generally, I feel confident I can better solve problems by tinkering.
15. I am confident selecting the appropriate tools and equipment that I need to take something apart.
16. Generally, I feel confident making and tinkering in a classroom.
17. By and large, I would feel confident encouraging others to tinker.
18. Generally, I would feel confident promoting making and tinkering in the classroom to others.
19. I am generally comfortable exploring a new technique before I receive specific explanations or training.
20. I have a deep need to know how things work.
21. I typically enjoy making improvements on the things I take apart.

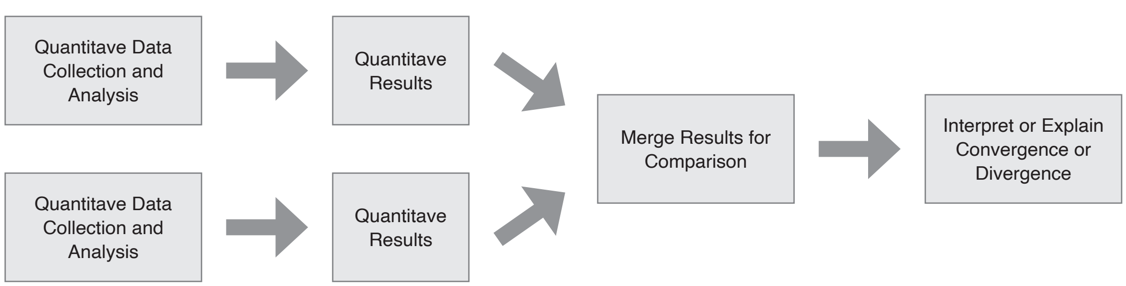
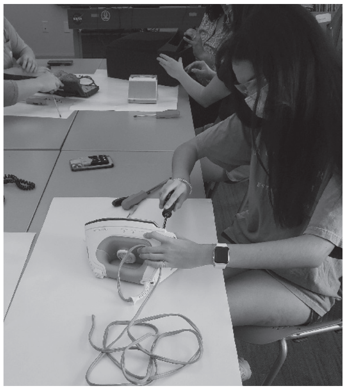
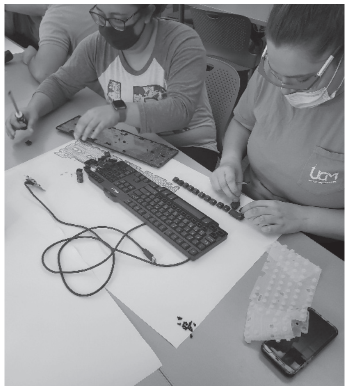


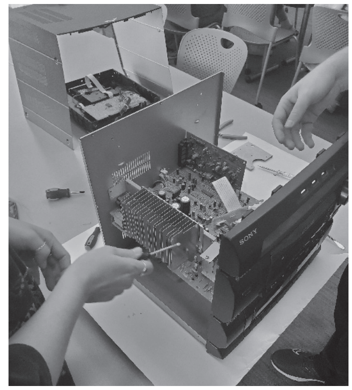
Figure 2. Concurrent Quan + Qual Parallel Mixed Methods Model Design



Iron



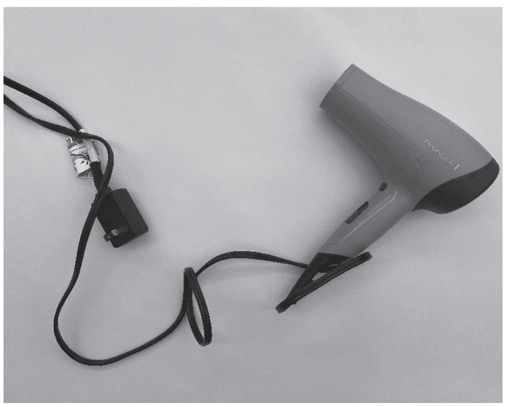
Keyboard



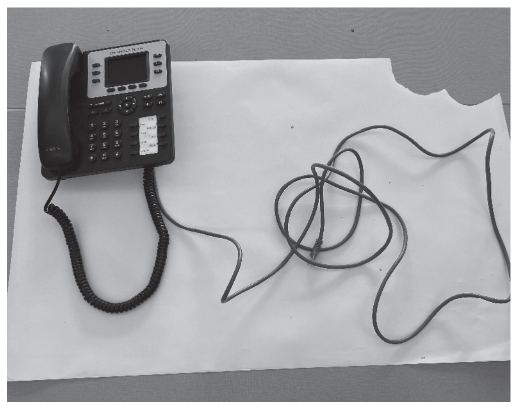
Stereo System

Figure 3. Pre-service teacher candidates beginning to take items/devices apart

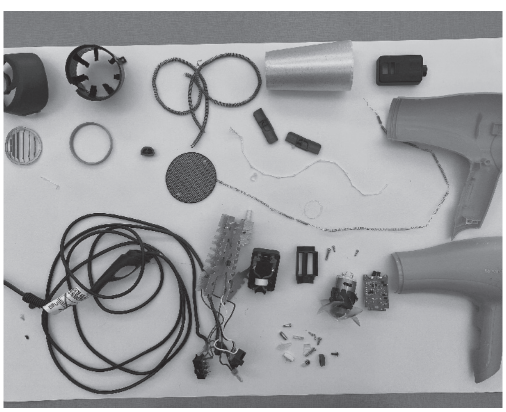
Once the items/devices were taken apart, the candidates displayed and discussed the parts they found, their understanding of how the equipment worked, and the potential future uses for the parts (see Figures 4. and 5.).



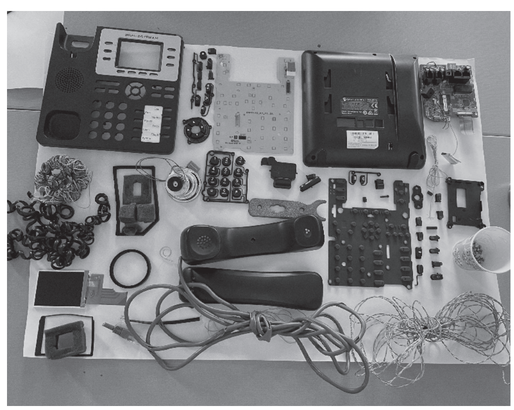
Before



Before



After



After

Figure 4. Pre-service teacher candidates displaying the hairdryer before and after taking it apart

Figure 5. Pre-service teacher candidates displaying the telephone before and after taking it apart

future classrooms based on the research question: How might the integration of tinkering and take-apart teaching methodologies in pre-service teacher education increase the technological and engineering self-efficacy of pre-service elementary teacher candidates?

The following investigation occurred within two different class sections. The research concluded at the end of the second-class meeting. To begin, the pre-service teacher candidates completed a brief survey related to their self-efficacy about tinkering and take-apart teaching methodologies. Then, the candidates were presented with a variety of items or devices. Using hand tools, the candidates deconstructed the items or devices to discover what was inside. Once the items or devices were taken apart, the candidates displayed and discussed the parts they found, their understanding of how the items or devices worked, and the potential future uses for the parts. At the conclusion of second-class meeting, the candidates once again rated their tinkering self-efficacy by completing the same pre-experiment survey instrument. Data were collected, and results from the pre- and post-survey on tinkering were recorded online through a Google Forms® survey. The researcher's notes based on pre-service teachers' discussions, researchers' observations, and photographs of the items or devices as they were taken apart and the photographs that displayed the found parts were also included as data. Additionally, the participants had the option to provide a short, written reflection.

Design

Quantitative and qualitative data were collected at the same time in a Concurrent Quan + Qual parallel mixed methods model design (Plano, Clark, & Ivankova, 2016). The main intention of this concurrent approach was to gather quantitative measures of tinkering and take-apart self-efficacy together with qualitative data of pre-service teacher candidates' understandings and explanations of the formation of those self-beliefs, and then mix that data to generate a more thorough and substantiated conclusion as illustrated in Figure 2.

Participants

The following investigation occurred within two different sections of a pre-service elementary teacher education class with a total of thirty-three participants. There were 31 female participants and 2 male participants. All participants completed both a pre- and post-tinkering and take-apart survey, and they also participated in the take-apart challenge. The researchers administered the tinkering and take-apart survey, the introduction of the take-part challenge, and conducted all discussions which occurred simultaneously within the class meetings.

Tinkering and Take-apart Self-Efficacy Survey

Tinkering and Take-apart Self-Efficacy was measured using a questionnaire designed by the researchers based on Baker, Krause, and Purzer's instrument (2008). Table 1. represents the twenty-one questions that were generated. The pre-service teacher candidates were asked to respond to the statements on a Google Form® based on a five-point scale where 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree nor Disagree; 4 = Agree; and 5 =Strongly Agree. The survey was presented at the beginning of the initial class meeting and again at the culmination of the second class meeting.

Tinkering and Take-Apart Challenge

Following the completion of the first Tinkering and Take-apart Survey, the pre-service teacher candidates were introduced to a variety of non-working items or devices, including an iron, a hairdryer, a laptop computer, a computer keyboard and a mouse, a compact stereo system, a telephone, and an alarm clock. The researchers introduced McLellan's (2013) Guide to Deconstructing, *Things Come Apart: A Teardown Manual for Modern Living* to the candidates and then gestured to the items or devices and asked the candidates what they thought they would be doing during the class meeting. The candidates made the connection between the book and the items or devices in the room and then the candidates were randomly selected to be a member of a group of two. One member of the class worked independently, as there was an odd number of students in the course. The groups proceeded to the items or devices and made their choice of what they wished to take apart. After selecting their item, the candidates used hand tools to deconstruct these items to discover what was inside as seen in Figure 3. The take-apart dismantle was paused toward the end of the initial class meeting and immediately resumed at the beginning of the second class meeting.

RESULTS

To examine the quantitative findings, a Chi-square test of independence was utilized to summarize the relationship between the pre-survey and the post-survey results. This technique can be implemented to establish whether there is a difference between the expected frequency and the corresponding observed frequency (Bartz,

Table 2. Association Between Results from Tinkering and Take-apart Surveys

statement	*n*	*p* value	mean pre-survey	mean post-survey
06	33	0.038	3.15	4.51
09	33	0.024	3.94	4.82
17	33	0.037	3.36	4.52

Table 3. Pre-service Teachers' Reactions to Take-apart

Main Theme	Example and Researcher Notes	Subthemes
Hesitation	***"I haven't taken things apart before."*** (Participant is staring at the iron and not moving or touching anything. Partner is also staring.)	Insecurity
	"How do we start?" (Participant is holding a flathead screwdriver and looking at the screws on the bottom of the telephone. The partner is also holding a flathead screwdriver and begins to loosen a screw. The first participant watches and does not attempt to use the screwdriver.)	Caution
	"I feel like we should get a screwdriver, but I'm not sure how to do this. What tools? I don't want to mess up." (Participant is holding the keyboard, but not examining it. Participant is looking at other pairs and observing that some sets are gathering tools.)	Lack of Confidence
Confusion	***"We should get a bunch of tools. A bunch of tools!"*** (Participant is rotating the laptop around and opening and closing the laptop screen. The partner shakes her head and grabs a handful of tools that were in a pile on the supply table.)	Inquisitiveness
	"I think this is a battery, 'cause it just looks like a battery, but I'm not sure." (Participant is taking apart a stereo and is pointing to a small resistor on the circuit board.)	Problem Solving
	"How does this not melt?" (Participant is taking apart the hairdryer and is touching the paper heatshield.)	Critical Thinking
Discovery	***"It's a magnet!"*** (Both partners have just removed the round component inside a stereo speaker. A loose screw is hanging from the speaker and while holding the speaker, the partners notice the metal screw is attracted to the round component.)	Amazement
	"Now I am wondering about my curling iron, my straightener, and everything…"	Connections
	"I've never thought about how things are made." (The participant that has taken apart the hairdryer has now arranged the parts and is staring at the parts. She turns to her partner and makes this statement.)	
	"I feel powerful!" (As the participants are beginning to clean up after the first class meeting, participant looks down at the partially deconstructed volt amp meter.)	Confidence

1998). In this study, analysis began with the reference to the null hypothesis and the alternative hypothesis designed to investigate these ordinal categorical variables. The null hypothesis stated there was no significant difference between the responses on the pre-survey and the responses on the post-survey. The alternative hypothesis stated there was a significant difference between the responses on the pre-survey and the responses on the post-survey. Although all twenty-one survey statements indicated a mean increase in self-efficacy ratings following the in-class take-apart challenge and the post tinkering and take-apart survey, the Chi-square test of independence was performed to further examine the relationship between the pre-survey statements and responses on the post-survey. Overall, the results of the Chi-square tests were statistically significant for three of the twenty-one statements.

Statement 6 “I basically understand the connection between tinkering and learning in the classroom, Statement 9 “I have a general understanding of what it means to tinker,” and Statement 17, “By and large, I would feel confident encouraging others to tinker” all showed $p < 0.05$. A low p value on a Chi-square indicates there is a high correlation between the two data points and summarizes the relationship between the categorical variables (Bartz, 1998). (See Table 2.). Overall, these statements reflect the change in participants' understanding about what it essentially means to tinker, the association of tinkering and learning in the classroom, and the self-assurance to discuss and encourage others to tinker.

The qualitative research conducted in parallel with the quantitative research also provided a rich investigation to understand the thoughts, experiences, and conclusions of the participants. Candidates offered a wide range of comments displaying anxiety, confusion, and personal connections to take-apart and tinkering. The researcher's notes based on antidotal records of the participants discussions, researcher observations and photographs of the participants as they were taking apart the items/devices, as well as the photographs that displayed the found parts were also included as data. Moreover, the participants had the option to provide a short, written reflection. Three major themes emerged from the qualitative analysis. These themes included hesitation, confusion, and discovery. In addition, nine subthemes of insecurity, caution, lack of confidence, inquisitiveness, problem-solving, critical thinking, amazement, connections, and confidence were also identified (See Table 3).

The written reflection from one participant highlighted evidence of the three major themes:

> After class last Thursday I had never really taken something completely apart. After seeing all the tiny little screws, wires, tape, and control panels it was insane to think that either a person or machine in a factory had made these things from scratch into an actual item we can use.

DISCUSSION

Findings from this pilot study generated noteworthy information about the integration of tinkering and take-apart methodologies in pre-service teacher education and the pre-service teacher candidates' technological and engineering self-efficacy. Although the quantitative and qualitative findings in this study may have yielded a more thorough understanding and explanation about how the integration of tinkering and take-apart methodologies in pre-service teacher education might increase the technological and engineering self-efficacy of pre-service teacher candidates, the findings have also raised additional questions. The study was limited by the small sample size of thirty-three participants. Moreover, there are limitations with the rating scale survey since rating scales may be subjective. The value a participant assigned to a particular statement may differ from another participant's interpretation of the same statement on the tinkering and take-apart survey.

The study was directed by the research question: How might the integration of tinkering and take-apart methodologies in pre-service teacher education increase the technological and engineering self-efficacy of pre-service elementary teacher candidates? The aim of this concurrent research approach was to gather quantitative measures of tinkering and take-apart self-efficacy along with qualitative data of pre-service teachers' understandings and explanations of the formation of those self-beliefs, and then mix that data to deliver a more thorough and substantiated conclusion which may drive the next steps.

When merging the data, a convergence appeared while comparing the candidates' own descriptions of their self-efficacy with the three statistically significant statements from the qualitative tinkering and take-apart survey. For example, when an elementary teacher candidate examined the volt amp meter she was taking-apart, she proclaimed, “I feel powerful!” That qualitative data statement coded under the subtheme of “confidence” which converges with survey

Statement 6 "I basically understand the connection between tinkering and learning in the classroom, Statement 9 "I have a general understanding of what it means to tinker," and Statement 17, "By and large, I would feel confident encouraging others to tinker."

Additionally, qualitative statements that coded the theme of "hesitation," akin to "I feel like we should get a screwdriver, but I'm not sure how to do this" occurred before the candidates began taking apart the equipment. The items that coded under the theme of "discovery" such as "I've never thought about how things are made" occurred toward the end of the take-apart challenge. These examples may explain the timing that led to the statistically significant Statement 9 "I have a general understanding of what it means to tinker."

Finally, the findings of Statement 17 "By and large, I would feel confident encouraging others to tinker" provides deeper understanding when mixed with the change in thinking documented by the qualitative explanation of a candidate:

> Growing up I never considered the fact that my siblings and I 'tinkered.' We grew up in the woods building forts, designing pully systems, creating bows and arrows out of sticks and twigs. As we got older, it turned to taking apart old computers, or taking scraps from our barn supply of things and recycling them to create new objects…makes me think back to those things and how they relate to… how young children tinker, ask questions, solve problems, get creative, etc. It is quite fascinating to realize I did these things without fully understanding the implications of them.

The results provided insight into a potential increase of pre-service teacher candidates' self-efficacy in technological and engineering through the integration of tinkering and take-apart.

CONCLUSION

The purpose of this study was to examine the tinkering and take-apart self-efficacy of elementary pre-service teacher candidates and their confidence in utilizing tinkering and take-apart activities in their future classrooms. This investigation as supported by Moye (2019), preparing students to become technological and engineering literate should not be left to chance. Furthermore, as suggested by Brophy et. al. (2008), "learning engineering requires identifying opportunities to conceive of something new, comprehending how something works, and researching and applying knowledge to construct something novel and appropriate for others" (p. 384). The findings of this study indicate an increase in technological and engineering self-efficacy for the pre-service teacher candidates. This may have additional implications for the inclusion of tinkering and take-apart teaching methodologies in the elementary classroom, indicating the need for additional research. Elementary children can engage in engineering activities and appear to be quite motivated and proficient, which influences their engineering identity (Capobianco, et. al, 2014). Since elementary children have shown an increase in their engineering self-efficacy by engaging in engineering activities, teachers who have had a personal experience with tinkering and take apart may be the key to ensure hands-on integrated STEM challenges do occur in the elementary classroom and are not left to 'chance.' Tinkering and take-apart teaching methodologies may benefit both the teacher lacking the self-efficacy to integrate technological and engineering processes and practices in their own classroom, eventually influencing their students who will be entering a workforce filled with the prediction of future shortages in the fields of science, technology, engineering, and math. These students could easily be denoted as Mrs. Doster's Tori. Elementary classroom teachers and their technological and engineering self-efficacy may become the prominent focus of STEM integration through tinkering and take apart implicitly stated by Cotabish, Dailey, Robinson, and Hughes (2013) who articulate "elementary teachers are the gatekeepers to fostering the gifts and talents of future STEM innovators" (p. 216).

Leah R. Cheek *has served as a public-school teacher, laboratory preschool director and adjunct professor. She is currently a Doctoral Academy Fellow Ph.D. candidate in Curriculum and Instruction at the University of Arkansas, Fayetteville.*

Vinson Carter, Ph.D*. is an Associate Professor of STEM Education at the University of Arkansas, Fayetteville.*

Michael K. Daugherty, Ed.D*. is a Distinguished Professor of STEM Education in the College of Education and Health Professions at the University of Arkansas, Fayetteville.*

REFERENCES

Archer, L., Moote, J., MacLeod, E., Francis, B., & DeWitt, J. (2020). ASPIRES 2: Young people's science and career aspirations, age 10-19. London: UCL Institute of Education.

Baker, D., Krause, S., & Purzer, S. (2008). Developing an instrument to measure tinkering and technical self-efficacy in engineering. Paper presented at the ASEE Annual Conference, Pittsburgh, PA.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84(2), 117–128.

Bartholomew, S., Strimel, G., Zhang, L., & Homan, J. (2018). Examining the potential of adaptive comparative judgement for elementary STEM design assessment. *Journal of Technological Studies*, 44(2), 58-75.

Bartz, A. (1998). *Basic statistical concepts* (4th ed.). New York: Pearson.

Brophy, S., Klien, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, Jul2008(3), 369-387.

Brophy, S., & Mann, G. (2008). Teachers' noticing engineering in everyday objects and processes. *ASEE Annual Conference and Exposition*, Conference Proceedings, 1(1).

Capobianco, B., Yu, J., & French, B. (2014). Effects of engineering design-based science on elementary school science students' engineering identity development across gender and grade. *Research in Science Education*, 45(2), 275-292.

Carter, V., Kindall, H., & Elsass, A. (2016). Integrating design and social studies: Engineering a play. *Children's Technology and Engineering*, 20(3), 10-13.

Cook K., & Bush, S. (2018). Design thinking in integrated STEAM learning: Surveying the landscape and exploring exemplars in elementary grades. *School Science and Mathematics*, 118(3-4), 93-103.

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The effects of a STEM intervention on elementary students' science knowledge and skills. *School Science Mathematics*. 113(5), 215-226.

Cunningham, C. M. (2009). Engineering is elementary. *The bridge*, 30(3), 11-17.

Daugherty, M., & Carter, V. (2018). The nature of interdisciplinary STEM education. In M. J. de Vries (Ed.), *Handbook of Technology Education* (pp. 159–172). Springer International Publishing.

Daugherty, M, Carter, V., & Sumner, A. (2021). Standards for technological engineering literacy and STEM education. *Technology & Engineering Teacher*, 76(1), 32-37.

Heroman, C. (2017). *Making and tinkering with STEM: Solving design challenges with young children*. Washington, D.C.: NAEYC.

Hsu, M. C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research* (J-PEER), 1(2), 5.

International Technology and Engineering Educators Association. (ITEEA) (2020a). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. Reston, VA: Author.

International Technology and Engineering Educators Association. (ITEEA) (2000b). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Kang, E. J., Donovan, C., & McCarthy, M. J. (2018). Exploring elementary teachers' pedagogical content knowledge and confidence in implementing the NGSS science and engineering practices. *Journal of Science Teacher Education*, 29(1), 9-29.

Kelley, T., & Knowles, G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11), 6-11.

Leon, A., Davis, L., Kraemer, H. (2010). The role and interpretation of pilot studies in clinical research. *Journal of Psychiatric Research*, 45(3), 626-629.

McLellan, T. (2013). *Things come apart: A teardown manual for modern living*. New York: Thames & Hudson.

Miller, B. (2021). Developing interest in STEM careers: The need to incorporate STEM in early education. *School Science and Mathematics*, 112(6), p. 1-2.

Moye, J. J. (2019). Preparing technology-and-engineering-literate students--it's not left to chance. *Technology & Engineering Teacher*, 78(7), 8-13.

National Science Foundation. (2018). Mathematics and science education: Enrollment in postsecondary education. Arlington, VA. Retrieved September 18, 2021 from https://www.nsf.gov/statistics/2018/nsb20181/report/sections/elementary-and-secondary-mathematics-and-science-education/transition-to-higher-education#enrollment-in-postsecondary-education

Novak, E., Wisdom, S. (2018). Effects of 3D printing project-based learning on preservice elementary teachers' science attitudes, science content knowledge, and anxiety about teaching science. *Journal of Science Education and Technology*, 27(5), 412-432.

Plano Clark, V. & Ivankova, N. (2016). *Mixed methods research: A guide to the field*. Thousand Oaks, CA: Sage.

Putri, S., Sumiati, T., & Larasati, I. (2019). Improving creative thinking skill through project-based-learning in science for primary school. *Journal of Physics: Conference Series*, 2(1157), 1–6.

Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. In Honey, M., & Kanter, D. (Eds.), *Design. Make. Play: Growing the next generation of STEM innovators* (pp. 163–181). New York: Routledge.

Robinson, A. (2017). Developing STEM talent in the early school years: STEM starters and its next generation scale up. In K. S. Taber & M. Sumida (Eds.) *Teaching gifted learners in STEM subjects: developing talent in science, technology, engineering and mathematics*. London: Routledge. pp 21-30.

Robinson, A., Adelson, J., Kidd, K., & Cunningham, C. (2018). A talent for tinkering: developing talents in children from low-income households through engineering curriculum. *Gifted Child Quarterly*, 62(1), 130-144.

Swift, C., Strimel, G., Bartholomew, S., & Yoshikawa E. (2018). Cultivating a family of innovators through design thinking. *Children's Technology and Engineering*, 22(4), 7-11

U.S. Bureau of Labor Statistics. (2021). *Employment in STEM occupations*. Employment projections. Table 1.11. Employment in STEM occupations, 2020 and projected 2030. Retrieved September 30, 2021 from https://www.bls.gov/emp/tables/stem-employment.htm#2