Rodriguez, S., Smith, S., & Harron, J. (2021). Analyzing the development of science and mathematics teachers' maker-centered philosophy and instructional practices. *Contemporary Issues in Technology and Teacher Education, 21*(1), 97-125.

Analyzing the Development of Science and Mathematics Teachers' Maker-Centered Philosophy and Instructional Practices

Shelly Rodriguez
The University of Texas, Austin

Shaunna Smith
The University of Hawai'i System

Jason Harron
Kennesaw State University

Making is an iterative process of designing, building, tinkering, and problem-solving, resulting in the creation of personally meaningful artifacts. Fueled by recent developments in affordable, safe, and easy to use digital fabrication technologies, making has been embraced by educators the world over. While educational scholarship is developing an increasingly complex understanding of the practices and pedagogies needed to support making in the classroom, there has been limited research associated with the preparation of teachers and their development of maker-centered instructional practices. In this embedded case study, the authors examined artifacts produced by 13 secondary preservice and in-service science, technology, engineering, or mathematics (STEM) classroom teachers engaged in long-term maker professional development as part of a microcredentialing program. Analysis of these artifacts uncovered an array of motivations for engaging with classroom making, illustrated how participants implemented their maker philosophies in secondary STEM classrooms, and suggested the need for additional research on and models of maker-centered programs in teacher preparation.

Making is an iterative process of designing, building, tinkering, and problem-solving, resulting in the creation of personally meaningful artifacts. Fueled by recent developments in affordable, safe, and easy to use digital fabrication technologies, making has been embraced by educators the world over (e.g., Bullock & Sator, 2015; Silva & Merkle, 2017; Wilson & Gobeil, 2017) as well as in the United States (e.g., Calabrese Barton & Tan, 2018; Clapp et al., 2016). Additionally, interest has grown among science and mathematics educators who see the promise of making and the associated maker movement as a means of enhancing K-12 students' active participation and personal connections (Bevan, 2017; Tofel-Grehl et al., 2020).

While educational scholarship is developing an increasingly complex understanding of the practices and pedagogies needed to support making in the classroom, research associated with the preparation of teachers and the development of their maker-centered instructional practices has been limited. In this embedded case study, we examined artifacts produced by 13 secondary preservice and in-service science, technology, engineering, or mathematics (STEM) classroom teachers engaged in long-term maker professional development as part of a microcredentialing program.

Analysis of these artifacts provided insight into the ways these teachers approached making, both philosophically and practically, and the emergent opportunities and challenges faced when engaging with maker education are described. Findings can inform teacher preparation programs and professional development offerings that incorporate maker education.

Literature

The literature in this section describes how making can broaden participation in STEM education, presents perspectives on maker-centered instruction, and suggests personal, lived experiences as an aspect of preparing teachers for making.

Bringing Making Into the STEM Classroom – Access for All

Many of the practices of making align closely with the NGSS Science and Engineering Practices (NGSS Lead States, 2013). For example, during the act of making, students have the opportunity to ask questions and define problems, develop and use models, construct explanations and design solutions, and obtain, evaluate, and communicate information about their creations (Rodriguez et al., 2019). Making also supports *design thinking* (Jordan & Lande, 2016), which involves cycles of empathizing, defining problems, ideation, prototyping, and testing. Design thinking can help develop student confidence while also increasing proficiency with various current technologies and tools.

In addition, participation in maker-centered activities can engage students in efforts that align with their interests and sense of themselves (Vossoughi & Bevan, 2014). It can also provide opportunities to develop the habits of mind associated with the maker mindset, such as playfulness, resilience, collaboration, and reflection (Martin, 2015). Thus, the use of making as an approach to STEM education has been recognized by the National Science Foundation (NSF) as having the potential to broaden participation in STEM while also fostering innovation and increasing student retention (NSF, 2017).

Traditionally, the practices of making have thrived in learning environments such as community makerspaces, garages, libraries, and museums (Calabrese Barton & Tan, 2018; Clapp et al., 2016). These informal learning environments allow individuals the freedom to create at their own pace without the constraint of specific guidelines governing their final product. An increasing number of schools are adding open spaces that are dedicated to making, usually referred to as makerspaces or fabrication labs. The culture of curriculum standards, however, often isolates making to after-school programs, extracurricular activities, and nontested subjects (Harron & Hughes, 2018; Peppler et al., 2016), thus reducing access for students and communities outside of those domains. Thus, bringing making into classrooms, which serve students from all walks of life, can expand the reach of making and encourage inclusivity.

For the practices and technologies of making to thrive, teachers need support in fostering the agency of their students, promoting active participation, and leveraging the cultural resources of the classroom (Bevan, 2017). Thus, more must be done to prepare future STEM classroom teachers to implement these practices. A recent national survey revealed that only 17% of undergraduate teacher preparation programs in the United States had a makerspace available to their preservice teachers and that only about half provided an opportunity to learn about maker-education and the associated technologies (Cohen, 2017). Without maker-based experience as part of their teacher preparation, future STEM educators will likely remain unaware of how these inventive practices can benefit their students.

Maker-Centered Instruction

Grounded in constructionism (Papert, 1991), making promotes knowledge acquisition through the creation and sharing of personally meaningful artifacts. However, no single school of thought exists on what constitutes the instructional practices needed to support making. For example, the use of the previously mentioned design thinking process has been viewed as a method of educating about making (Bowler, 2014). In contrast, Bullock and Sator (2015) proposed four elements of maker pedagogy, including principles of design, artistic creating, ethical hacking, and adapting old devices for new uses. Cohen et al. (2017) proposed “makification,” which involves teachers integrating maker mindsets (i.e., autonomy, creation, iteration, and sharing) into the formal K-12 classroom context through enhancing existing content-focused lessons and encouraging students to learn content by constructing artifacts.

Our study focused on making within the bounds of a secondary classroom and facilitated by a content area STEM teacher. Therefore, The Elements of Making (Rodriguez et al., 2018), described in this paper provide a useful framework. In this context, maker-centered instruction is defined as instructional practice that facilitates one or more of these elements (see Appendix A).

Preparing Teachers for Maker-Centered Instruction

Literature suggests that teachers make personal choices about what technology means in the context of their own classrooms and that these choices have important implications for their instructional practices (Ellis et al., 2020). For many educators, making is synonymous with the use of specific technological tools (e.g., 3D printing) rather than the theoretical underpinnings and habits of mind associated with making (Martin, 2015). Therefore, in addition to understanding relevant technologies, teachers must have opportunities to develop a philosophical understanding of maker-centered pedagogies, observe these instructional strategies in practice, implement them in their own lessons, and reflect on the outcomes. Thus, providing personal, lived classroom experiences for maker educators is essential in providing teachers with an occasion to apply theory-to-practice as they think like a teacher and enact teacher identities (Hammerness et al., 2005; Jones & Woglom, 2017).

Providing teachers with lived making experiences is central to understanding their perspectives on making and uncovering the barriers they face. For example, Jones et al. (2017) investigated preservice teachers' beliefs about formal making activities in K-12 settings. They found that the hands-on nature of the learning allowed for differentiated practices that may inspire longer retention. In enacting these activities with students, they found that making shifted the focus away from the teacher, which allowed for more student-centered teaching strategies. The authors also identified limitations of implementing these strategies posed by the internal barriers of the teachers' belief in their own abilities and technical knowledge and the external barriers of time constraints, access to maker technologies, and state standards.

The study featured in this article used qualitative analysis to examine artifacts produced by 13 preservice and in-service secondary STEM teachers who have engaged in long-term maker professional development as part of a university microcredentialing program. In this program each teacher created an open portfolio that documented their experience. This study specifically examined the content of two required sections within this portfolio, Maker Philosophy and Maker Education, and addressed the following research questions:

1. What motivation for engaging with maker education do participants express?
2. To what extent do the teachers' philosophy statements about making and maker education correlate with the maker-centered lessons they design and enact?
3. What constraints limiting classroom-based making are identified by the teachers?

Methods

Context

UTeach Maker (https://maker.uteach.utexas.edu/) is an optional microcredentialing program that is part of the UTeach STEM teacher preparation program at The University of Texas. It provides professional development and support for preservice and early career in-service teachers, as they develop the knowledge, skills, and community connections needed to support maker activities in the secondary STEM classroom.

In the program, teachers are provided with a maker mentor, maker-centered professional development, support for maker lessons and projects, and access to local makerspaces and they become part of a community via monthly cohort meetings and weekend workshops. To earn their microcredential, each teacher must complete an open portfolio over a minimum of two academic semesters. The portfolio is a public website, called a Maker Showcase, that serves as a digital online archive of their work in making.

The goal of the Maker Showcase is for teachers to create a personal expression of their maker journey that can be shared with others and serve as a tool for ongoing reflection. The Maker Showcase includes four documented areas: Maker Philosophy, Maker Project, Maker Community, and Maker Education. Teachers are responsible for providing evidence for each area, including photos, blog posts, personal reflections, or other products that reflect their progress or ideas.

A description of the purpose, requirements, and rubric can be found at https://maker.uteach.utexas.edu/what-maker-showcase. At the end of a teacher's time in the program, the Maker Showcase is submitted for external review and presented publicly to the community. Sample showcases can be found at https://maker.uteach.utexas.edu/uteach-maker-fellows-showcase-examples

As of fall 2019, the program had served 45 preservice and in-service teachers. Twenty had completed the program, and program enrollment at that time was 22 preservice teachers, three in-service teachers, and a waiting list of others.

Participants

This research study focused on 13 participants who had earned their microcredential by the end of spring 2018. Table 1 provides demographics of the participants that were the subject of this study.

Table 1 Participant Demographics (13 total)

Teaching Status	Gender	Ethnicity	Teaching Discipline
11 (85%) Pre-service 2 (15%) In-service	9 (69%) Female 4 (31%) Male	7 (54%) White 4 (31%) Hispanic 2 (15%) Asian	4 (31%) Biology 3 (23%) Chemistry 3 (23%) Mathematics 2 (15%) Physics 1 (8%) Engineering

Data Sources

As an embedded case study (Yin, 2003), the unit of analysis centered on the Maker Showcase produced by each participant. Data for this research study included two out of the four sections of the Maker Showcase, (a) Maker Philosophy and (b) Maker Education, more specifically, artifacts generated as part of a maker-centered lesson enacted in a K-12 classroom. We compared these two sections to gain insight into the ways in which participants translated their ideas about making, as represented in their philosophies on classroom action in their showcase lessons.

The Maker Philosophy section promotes an understanding of the educational and ideological roots that underlie maker-centered learning. It encourages participants to explore the origins of making as a pedagogical tool in the context of other student-centered orientations, like constructivism and constructionism. In the Maker Philosophy section, participants are asked to reflect on making from both historical and cultural perspectives. In this section, participants also articulate a personal philosophy of making and provide a rationale for the integration of making into their instructional practice.

The Maker Education section asks participants to make connections between personally meaningful making and K-12 education. As part of this section, participants had to describe and upload artifacts in support of a maker-centered lesson they had enacted in a K-12 STEM setting. Artifacts included a lesson plan, handouts, slides, samples of student work, and lesson reflections. This set of lesson artifacts served as the data source for analysis. Thus, in the following sections this body of work, taken together, will be referred to as the showcase lesson.

Table 2 provides contextual information, at the time of the study, for the 13 participants. The 11 preservice teachers in this study designed and taught their showcase lesson during their student teaching semester. The two in-service teachers taught the showcase lesson in their own classrooms. All showcase lessons represented first iterations, and lesson reflections provided important insight into the experience of the participants and their ideas for next steps.

Analysis

Qualitative techniques were used to analyze the participants' Maker Philosophy sections and showcase lessons. For both, a team of three researchers used The Elements of Making matrix as a coding framework.

Prior to coding, all Maker Philosophy text and Showcase Lesson files were copied from the Maker Showcase websites and saved as Rich Text Format (RTF) to enhance compatibility with the online coding platform Dedoose. Data were analyzed in two cycles following the guidelines by Miles et al., (2014).

During the first cycle, all three researchers independently coded two of the participants using deductive coding based on the The Elements of Making matrix. An iterative data-driven process was used to establish additional codes as they emerged from the data (as in DeCuir-Gunby et al., 2011). All three researchers met to debrief, which included comparing and discussing our independently coded data, and verifying, modifying, and refining codes until agreement was met.

Interrater reliability was measured using Fleiss' Kappa, which was .764 where observed agreement was .871 and expected agreement was .455. This ratio is considered substantial agreement (Fleiss et al., 2003). From that point, remaining data were distributed amongst the three researchers to ensure that each data source was coded by at least two researchers. During the second cycle of analysis, data were constantly compared and reanalyzed for new codes, categories, and emergent themes.

In addition to these qualitative coding techniques, the Showcase Lesson materials were coded using binary presence-absence coding (i.e., present = 1, absent = 0) to identify if participants included The Elements of Making in their lessons. Quantifying the data in this way allowed us to establish mean scores for individual participants and individual criteria for each element. Interrater reliability between the three coders was measured using Fleiss' Kappa, which was .631, where observed agreement was .722 and expected agreement was .247. This ratio is considered substantial agreement (Fleiss et al., 2003). As part of the analysis, coding frequencies were compared between each participants' Maker Philosophy and showcase lesson so we could better understand the theory-to-practice connection in what they said about making and what they did when enacting maker-centered instruction.

Table 2 Description of Participants

Participant Name Teaching Status/ Discipline	Showcase Lesson Description
Erin Preservice/Biology	Biology students play a game that models natural selection. Students use a plastic egg to make an organism, representing their adaptations.
Mariana Preservice/Biology	Biology students make quilt squares on genetics concepts with craft materials, copper tape, and LEDs. Squares combine to form a collaborative paper quilt.
Holly Preservice/Chemistry	Chemistry students work as an independent museum professional and to design a series of exhibits about water and its properties.
Adam Preservice/Physics	Physics students build a base car using wooden parts, collide cars, and must redesign cars based in challenges related to momentum.
Kevin Preservice/Chemistry	Chemistry students build a model of the electron cloud using LEDs wired in parallel and breadboards.
Alaina Preservice/Chemistry	Chemistry students work in groups to make a website that they can share with others to educate them about an ecological issue of their choice.
Mia Preservice/Mathematics	Algebra 1 students create their own measurement system and use it to measure objects and convert between their system and the standardized systems.
Noah Preservice/Engineering	Engineering students work in teams to create a compound machine designed to accomplish a specific mechanical task.
Francisco Preservice/Physics	Physics students create an interactive museum exhibit to educate the community about light, sound, and the history behind them.
Esha Preservice/Biology	Chemistry students are introduced to making by creating a bar of soap in a chemistry lab and designing their own laser-cut soap dish.
Nickie Preservice/Mathematics	7th grade math students make an artifact to represent their understanding of various mathematical concepts using a variety of high- and low-tech tools.
Avery In-service/Biology	7th grade life science students to design an interactive 3D model of a plant or animal cell that would be engaging for younger students.
Layla In-service/Mathematics	Geometry students use cardboard to make a geometric sculpture that is personally meaningful to them.

Findings

Motivation for Engaging in Maker Education

Our first research question focused on participant motivations for engaging in making and wanting to bring it to their classrooms. Why would teachers add to an already heavy workload to embark on a year-long professional development journey? Why would they work to change their own teaching practice and often go against the culture of the schools where they teach? An analysis of the Maker Philosophy sections for each participant provided insight. This section described several different motivations for making that emerged across the data (see Table 3). While some participants emphasized one aspect more than others, the themes highlighted here were common across all the maker statements.

Table 3 Participant Motivations for Engaging With Maker Education

Participant	Early Maker Experiences	Empowering Students	Dissatisfaction With STEM	Making for All
Erin	x	x	x	x
Mariana	x		x	x
Holly	x	x	x	x
Adam			x	x
Kevin	x		x	x
Alaina	x	x	x	x
Mia		x		x
Noah	x	x	x	
Francisco	x	x	x	
Esha		x	x	x
Nickie	x	x		x
+Avery	x	x	x	x
+Layla		x	x	X

Note. + Denotes in-service teacher

Early Maker Experiences

An analysis of philosophy sections showed that many participants developed their interest in making early in life. Nine of 13 participants (69%) referenced childhood experiences with making that were central to their vision of themselves and their confidence in what they could do.

This sentiment was communicated in the opening passage of Francisco's philosophy. He stated that making was rooted in a connection to his father: "As an immigrant from Mexico, my father had to create all sorts of workarounds to make a living.... On the days he would take me to work, I would notice the ingenious ways my father did construction." Francisco went on to describe how his father would provide him with challenges onsite, and he would make things to address these challenges. He recalled "making a ramp so that I could use a wheelbarrow to lessen my work. I still remember the proud feeling I had because of how much work I had saved myself!"

In another example, Noah's childhood story showed his youthful interest in making as he described a radio set he was given, one that an older cousin could not get to work. He related that he "used a coil wound around a Quaker Oats box, and a galena crystal, and cat's whisker electrode for a detector. My devotion to trial and error rewarded me with broadcasts of baseball games and local radio shows."

Stories of this kind were woven into the philosophies of almost all participants. Alaina's philosophy described building benches with her father, attending Home Depot workshops, and learning to knit from her mother and grandmother. Nickie told stories about how she grew up sewing, tinkering, and crafting but did not have the label of making to unify them. From early experiences like quilting to building cars, the positive making experiences of their youth made a lasting impression on the participants in our program, and they went on to describe these experiences as leading to their interest in maker education.

Empowering Students Through Making

In describing their motivation to make, the participants displayed an emerging sense of confidence that they hoped to share with their students. At the end of the story about his father, Francisco said, "These are my earliest memories of making, and I hope to transfer this feeling of empowerment to my students." Noah echoed him by saying of his radio building endeavors, "I want to bring that same kind of experience to my students."

Our analysis showed that the act of making, as children or as adults, provided an enhanced sense of confidence related to participants' own abilities. Furthermore, this sentiment became part of how they viewed the purpose of making generally. For some, like Alaina, this was a rediscovery of latent confidence around making. For others, like Esha, a first-time maker, it was embarking on a new and sometimes scary journey.

Each participant communicated a deep desire to pass on this sense of empowerment to their students. For example, Holly stated, “As a teacher, I feel responsible for providing my students with the space to develop their confidence and self-efficacy. I believe that these talents can be built simply by allowing kids to create and build useful and beautiful things.”

Each of the participants in the program described their belief that making provides agency and increased confidence. Ten participants (77%) also said that this empowerment could lead to their students becoming the problem-solvers and leaders of the future. In Esha’s philosophy section, she said, “If teachers can incorporate maker ideas and practices within the classroom, they prepare their students to go out in the world and be confident in what they can do to bring about changes that are necessary in society.” This sentiment was also captured in Adam’s philosophy section when he said, “Making fosters thinkers. These thinkers could then go onto creating some of the world’s greatest advancements, and the process would have all started in our classrooms.”

Dissatisfaction With Traditional STEM Instruction

In the philosophy sections, 11 of 13 participants (85%) suggested that their positive experiences with making gave them a sense of creative ownership and empowerment that had been missing from their traditional experiences with science and mathematics. They described the rift they felt as learners between their desire to be creative and their interest in STEM.

For instance, Erin said, “I grew up making things to wear, things to give, and things to display. However… I slowly learned that school was not a place for creating and making, especially not in my science classes.” Similarly, Kevin described being “required to choose between taking an art class or taking another science class.” Thus, his maker philosophy centered on “joining the creativity associated with less scientific subjects with the rigid logic we see in STEM” so that students like him “with interests in both art and science” need not choose one or the other.

Erin and Kevin’s dissatisfaction with the traditional model of STEM education led them to embrace making with their students. For many participants, making was seen as a way to connect two disparate worlds and allow students to express their creative selves in the STEM classroom.

Making for All

An analysis of participant philosophies indicated that they saw making as a way to help the students in their classes find their passion and develop confidence in their ability to create and contribute. However, 11 participants (85%) said that making takes resources and modes of instruction not currently accessible to all students. The philosophies indicated that, as educators, the participants were committed to providing inclusive maker experiences to students from all backgrounds as a way of empowering learning and connecting to their lived experiences.

In her philosophy section, Avery asserted that “building tangible products brings individuality and personality to the classroom. It allows students of various cultures and backgrounds to create and publish something they are inherently connected to.” Similarly, Alaina described her commitment to maker-centered instruction by saying, “As an educator my biggest goal will be to help get more students who belong to underrepresented populations to be more interested in exploring their interests.”

Adam echoed this statement, indicating his belief that beyond empowering individual students, making can also empower whole groups: “When making is accessible and equitable for all students, it gives every student a voice as they work, and it raises the presence and impact of marginalized groups.”

Elements of Classroom Making: What Maker Participants Say and Do

Our second question focused on the alignment between how the sentiments about making, as conveyed in participant philosophies, were reflected in their instructional practices. The next section provides findings of what participants said in their philosophy statements, in terms of the The Elements of Making used in the analysis, as well as the ways in which these elements were enacted in the maker-centered showcase lessons they designed and taught.

Alignment by Participant

Alignment is defined as the presence or absence of an element in both a participant’s philosophy and showcase lesson. For example, Esha’s philosophy and showcase lesson showed alignment in four of the six Elements of Making categories (see Appendix B). Esha’s lesson was an introduction to making for high school chemistry students that involved making a bar of soap and designing a laser-cut soap dish. For each participant, save one, there was a match between what they said (philosophy) and what they enacted (showcase lesson) for at least three out of six Elements of Making categories (Table 4).

For example, Francisco mentioned each of the six Elements of Making in his philosophy and enacted each of the six elements to some degree in this showcase lesson (6/6) giving him 100% alignment. In contrast, Layla showed alignment in only two of six element categories (creating a personally meaningful artifact and developing a maker mindset). The other categories were either mentioned in her philosophy but not enacted in her showcase lesson or vice versa. In Layla’s case, she enacted more elements of making in her lessons than she wrote about in her philosophy section.

Table 4 An Overall Comparison of Philosophy Statements and Showcase Lessons With Regard to Elements of Making

Participant	Create Personally Meaningful Products		Engage In Iterative Design & Fabrication		Demonstrate Characteristics Of A Maker Mindset		Collaborate and Connect With Community		Present Work Publicly		Use STEM		Categories in Alignment
	P	L	P	L	P	L	P	L	P	L	P	L	
Francisco	x	x	x	x	x	x	x	x	x	x	x	x	6/6
Kevin	x	x			x	x	x	x	x	x	x	x	5/6
Holly	x	x	x	x	x		x	x		x	x	x	4/6
Adam	x	x	x		x	x	x	x		x	x	x	
Erin	x	x		x	x	x	x	x		x	x	x	
Nickie	x	x		x	x	x	x	x		x	x	x	
Esha	x	x	x	x	x	x	x			x	x	x	
Noah	x	x	x		x		x	x			x	x	
Mariana	x	x	x		x		x	x		x	x	x	3/6
Alaina	x	x			x		x					x	
Mia	x				x		x	x	x				
+Avery	x	x		x	x	x	x	x		x		x	
+Layla	x	x		x	x	x	x			x		x	2/6

Note. x = presence of element. P = Philosophy. L = Showcase Lesson. +Denotes in-service teacher teaching in their own classrooms, all others were preservice teachers teaching in cooperating teacher classrooms.

Alignment Trends

Overall, there were high levels of overlap between participant philosophies and showcase lessons regarding having students creating something personal, having students collaborate in the classroom, and connecting to STEM content. There was also alignment in terms of Elements of Making missing in both philosophies and showcase lessons.

The iterative nature of making was mentioned in approximately half of the philosophies and addressed in approximately half of the showcase lessons. Examples of misalignment include the notion of developing a maker mindset. While important to participants philosophically, a focus on a maker mindset was often absent in showcase lessons. Conversely, while presenting work was an infrequent mention in philosophy sections, it was included in the majority of the showcase lessons. Table 5 provides a summary of these trends. The next section will describe them in detail.

Creating Personally Meaningful Products

Philosophy

An analysis of philosophies revealed that, across the board, personal relevance and the outlet for self-expression that it provided was a central feature participants' conceptualization of making. Each of the participants (100%) described a sense of personal ownership in their definition of making. For example, Erin suggested that the purpose of making was to create something that was "personally valuable." She also said that making allowed space for individuality and creativity. Likewise, Francisco wrote that making helps us to "tell a story about ourselves" and Adam defined making as "bringing your imagination to life."

Table 5 Trends in the Comparison of Philosophy Statements and Showcase Lessons

Label	Philosophy Statements	Showcase Lessons
Create personally meaningful products		
Total Participants	13	12
%	100	92
Engage in iterative design and fabrication		
Total Participants	6	7
%	46	54
Demonstrate characteristics of a maker mindset		
Total Participants	13	8
%	100	62
Collaborate and connect with community		
Total Participants	13	11
%	100	85
Present work publicly		
Total Participants	3	9
%	23	69
Use STEM		
Total Participants	9	11
%	69	85

Showcase Lesson

The vision of making as a personal process that involves agency and creativity was mirrored in the design of their showcase lessons. All participants (100%) described this element of making as important in their philosophy sections, and 12 participants (92%) included this element to some degree in their lessons.

Each of the showcase lessons illustrated high levels of student choice and allowed for an array of imaginative options. Thus, while the showcase lessons were typically constrained in terms of content and materials, participants regularly attempted to include student voice and freedom of expression in their lessons. For example, in Mariana's lesson, students were asked to create a paper quilt square that depict a selected genetics topic. Students were given the freedom to select from a wide array of materials for their creation. These unique creations were assembled and lit with LED lights at the end of the lesson to create a collaborative paper quilt. In her reflection on the lesson, Mariana said, "I gave them the freedom to choose how their final product would look, and I was not disappointed."

In another example, Adam's showcase lesson on momentum had each student putting together a car from precut wooden parts. While the materials for the car body were limited, students were provided with an opportunity to redesign their car to meet a challenge of their choosing. Students could choose to modify the car to go slower, withstand impact, or protect a "passenger" egg or they could decide on a modification of their own. Students were also given the opportunity to design their cars and "trick them out."

While the participants enacted lessons with high levels of student choice and agency, few homed in on the deeper concept of personal relevance. Explicit connections to the lived experiences of the students were uncommon. Only four showcase lessons (31%) included activities that overtly supported students in connecting the made product back to something from their daily lives or interests.

For example, Mariana's lesson provided creative choices for her students, but how the LED squares related to their lived experiences is unclear. In contrast, in Nickie's showcase lesson she asked her students to create a math artifact of their own invention. It could be a game, tool, or artistic element. The advanced level of her rubric called for the student to be able to connect their design back to a personal interest or experience. In another example, Layla asked her geometry students to create an artistic cardboard sculpture that was representative of themselves in some way.

The unpacking of their interests and passions did not come naturally to either Nickie's or Layla's students. Both teachers thus primed students by helping them reflect on their own values and motivations through warm-ups and surveys, including questions like, "What are your greatest talents?" "What kinds of things bother you in the world and how would you change them?" "What are some characteristics you like about yourself and want others to see in you?" and "What is the best gift you have received? Why?" These questions, as well as regular reflections on how making was meaningful to students, were used to foster a personal connection between the students, the content, and the products they made.

Collaborating and Connecting With Community

Philosophy

In their philosophies, all participants (100%) cited the necessity of a strong community to be successful in making. They recognized the value of both peers, mentors, and online maker forums as being integral in their personal acquisition of knowledge associated with the skills they were applying.

Participants argued that through their collective struggles they built bonds, learned, and came to appreciate different ways of doing things or different approaches and made friendships that they felt they could call on when they started new projects. For example, Adam said “attending maker events together and working on our Showcases together deepened the friendships I had with my peers. We motivated each other to go for the ideas coming out of our maker minds, no matter how ambitious they were.” Similarly, Alaina noted, “Having a support system was what helped me take failures as learning experiences. Reflecting on my journey as a Maker, I realize how important community and collaboration is.”

Participants also described the need for community in terms of sharing resources and ideas. In a reflection, Alaina went on to say, “Not all schools have access to really high-tech makerspaces so …working with the community could help students gain access to tools outside of their schools or to find possible solutions.”

In addition, participants portrayed the maker community as one of inclusion and acceptance. They described the maker community with terms like diverse, innovative, and accepting. Participants saw making as a space where everyone is welcome. For example, in her philosophy section, Nickie said, “The idea of making is not restricted to any people or group, since every person has the capacity to bring ideas to life.” This sentiment was echoed by Mariana, who said, “The Maker Movement is a great community of people from all walks of life and all ages,” and Adam, who said, “Forming a community of makers can bring diverse people together.”

Showcase Lesson

All participants (100%) gave some mention to the importance of collaboration and community in their philosophy section, which was reflected in the implementation of 11 showcase lessons (85%). However, in almost all cases, the showcase lesson focused on traditional forms of classroom collaboration over community. Most of the lessons had students working in pairs or teams to collaborate, and some had students provide peer feedback.

None of the lessons promoted student’s reliance on each other for help and encouragement, nor did any of the lessons extend their reach to the community outside of the classroom, either physically or virtually. The participants did not call on outside experts, connect their students with online communities, draw from local interest or cultural groups, or connect with other nearby makers to exchange ideas.

Using STEM

Philosophy

Another area of significant overlap was in the use of making to connect learners to STEM content. Nine participants (69%) mentioned this connection as an essential element of their maker philosophy. As STEM teachers, participants mentioned feeling that making was an important way to provide access to content for their students. However, the purpose of making with regard to STEM had multiple interpretations.

Eleven participants (85%) described making as a way to learn discipline-specific content. For example, in her philosophy section, Erin said, “I believe making helps children develop ideas in deep ways.” Seven participants (54%) also saw making as a way to apply previously learned STEM content to new tasks or real-world problems. In addition, the same number (54%) viewed making as a way to apprentice students into the processes of the discipline. One participant that conceptualized making in this way was Adam, who said,

> The greatest benefit from including making in the classroom is that students get to freely explore ideas and pursue what they are passionate about, which is what STEM learning is all about. Students can actually experience what it is like to be a scientist, mathematician, or engineer who continuously fails until finally achieving success.

Showcase Lesson

Given these contrasting views about the purpose of making with regard to STEM, the showcase lessons, not surprisingly, reflected various perspectives. While some lessons reflected the use of making as a way to learn new content, other participants chose to teach the content in more traditional ways and then have their students apply that knowledge through making after the fact.

The most common conception of connecting to STEM content reflected in the showcase lessons was using making as an avenue for assessment. Eleven showcase lessons (85%) had students include subject-specific content in their creations, and these creations were then assessed for accuracy with regard to these concepts. For example, Avery’s lesson had students creating interactive models for elementary school students as a way to learn about cells. Students were assessed on their knowledge of organelles during the process of constructing their models as well as during their final presentations to the other students. In this way, many participants in the study treated making as a performance task and used rubrics as assessment tools to evaluate the artifacts their students created.

Engaging in Iterative Fabrication

Given that making is by definition fabrication, this section will focus on the iterative nature of making, including tinkering, prototyping, and product revision. Interestingly, this was the element of making that showed significant overlap by being the least represented in both the philosophies and showcase lessons.

Philosophy

In our analysis, six participants (46%) addressed the idea of iterative design in their philosophies. In his philosophy section, Francisco mentioned the process of design and redesign he saw his father use to solve problems at construction sites. He discussed the importance of going through these stages and he noted the "work arounds" and the ingenious solutions that his father ultimately developed.

Similarly, Noah described the iterative process he went through building a crystal radio set that his older cousin could not get to work. He mentioned spending hours tinkering and noted that his "devotion to trial and error" soon allowed him access to broadcasts from across the country.

Showcase Lesson

Seven participants (54%) had opportunities for iterative fabrication in their lessons. One example of iteration in both philosophy and showcase lesson came from Adam, who said in his philosophy of making, "If an idea doesn't work, it can change. If a device fails, a student can tweak it." In his momentum showcase lesson, Adam provided his students with multiple opportunities to design, test, and redesign their wooden cars.

In contrast, Mariana regularly referred to making as "a process of trial and error" in her philosophy section, yet her showcase lesson did not provide students with this type of experience. In her reflection she mentioned being pressured by time since she was teaching a state-tested STEM subject.

Practicing Habits of a Maker Mindset

The previously mentioned elements of making showed a significant overlap between what participants communicated as important in their philosophies and how they enacted their showcase lesson with students. In contrast, developing habits of a maker mindset stood apart from this trend.

Philosophy

In their philosophy sections, all participants (100%) discussed the significance of making in developing habits of mind, like learning the value of play, developing persistence, and the need for revision and reflection. They also suggested that making was important for teaching students how to "work through problems," "fail forward," and see learning as something "playful and fun."

For example, Adam said that making can "bring out the child-like curiosity in everyone no matter their age… There would be no wrong answers in a classroom full of making." Likewise, to open her philosophy section Alaina said, "Things aren't always easy, but when you have an interest in what you are doing it is easier to tackle obstacles and turn those challenges into learning experiences."

Showcase Lesson

Though all participants noted the importance of developing a maker mindset, only eight participants (62%) paid explicit attention to this development in the design or implementation of their showcase lesson. For example, in his philosophy section, Francisco said, "Once my students hit a point of 'failure' I want them to be able to reflect and see that this 'failure' really is just another learning experience for next time they embark on a journey." While this reaction to failure may have happened for some of his students, Francisco's lesson did not illustrate explicit attention to this theme, either through class discussions, journaling, or by directly addressing this as a goal of the lesson.

In contrast, in her philosophy, Layla stated, "Your brain has to work to figure out why you failed and overcome it. You have to be okay with failing, and even celebrate failures." To foster this mindset, Layla built regular journaling prompts into her showcase lesson. She had students respond to prompts like, "In your own words, define making and the growth mindset," and "Compare and contrast the growth mindset and fixed mindset."

Another way that participants explicitly promoted a maker mindset with students was by sharing their own journey as a maker. Layla, Mariana, Nickie, and Esha all started their lessons by showing some of the items they themselves had made and discussing challenges, successes, and the need for persistence in the face of adversity.

Sharing Work Publicly

The public sharing of work with others is another element of making where there was a discrepancy between the philosophies and showcase lessons of participants.

Philosophy

Only three participants (23%) communicated that publicly presenting work was an important part of how they conceptualized making. In Kevin's philosophy, he noted that he wanted to be a maker educator so that his students could learn to make something new and show it off. In describing their experience with making, both Mia and Francisco reflected on the importance of creating something that can be shared for public benefit.

Showcase Lesson

Though most makers did not connect to the notion of the public presentation of work in their philosophies, nine participants' (69%) showcase lessons involved their students presenting their own maker products to others. Primarily, these presentations were summative, occurring at the final stage of the making process rather than formative, providing feedback for students to revise their work. In general, the presentation took the form of in-class presentations, gallery walks, or small group presentations. Only Erin, Esha, and Avery had their students present to audiences outside of the classroom, including university visitors and teachers and students from other classes.

Reflections on Classroom-Based Making

Our final research question asked what constraints limiting classroom-based making were identified by the teachers. In reviewing the reflections of participants, we recognized they were clearly aware of certain elements of making that were not captured by their showcase lesson. For example, in her lesson reflection Holly noted her lack of iteration saying, “Ideally, students could have had at least one additional day, where they could document issues with the original version and make specific improvements.”

In his reflection, Francisco noted his intention to have his students present their projects at a school-wide event, but the projects were not completed on time. In Mia’s reflection she noted that in the future she wanted to “create a need for students to collaborate.”

In addition to the self-awareness of the participants, several other important themes emerged around their experience with classroom making. First and foremost were the challenges they each faced. In their reflections, teachers suggested that restricted time, push back from campus culture, push back from students, and limited access to materials and high-tech tools as obstacles to enacting the lessons as they would want.

In terms of successes, many participants mentioned a perception of increased student engagement/confidence as a positive outcome and, while fewer participants mentioned the perception of an increase in student understanding, no participants mentioned feeling that their students were learning less than in traditional approaches. Table 6 shows the presence or absence of these themes for each participant.

Table 6 Perceptions of Classroom-Based Making From Lesson Reflections of Maker Participants

Participant	Pressures of Time	Push Back From Students	Push Back From School/ Department	Limited Access to Resources and Equipment	Rewarding Teaching Experience	Increased Student Engagement/ Confidence	Increased Student Understanding
Erin	x				x	x	x
Mariana	x	x			x	x	
Holly	x				x	x	
Adam	x			x		x	
Kevin	x	x			x	x	
Alaina	x	x	x				
Mia	x				x		
Noah					x	x	x
Francisco	x				x	x	x
Esha	x					x	
Nickie					x	x	
+Avery						x	x
+Layla		x					
Total	9/13 (69%)	4/13 (31%)	1/13 (8%)	1/13 (8%)	8/13 (62%)	10/13 (77%)	4/13 (31%)

Note. +Denotes in-service teacher teaching in their own classrooms, all others were preservice teachers teaching in cooperating teacher classrooms.

Not surprisingly, time pressure was the number one issue that participants faced when trying out their lessons. In addition to facing challenges, participants also made clear that they found the process of making with their students to be rewarding and that most noticed an increase in students' confidence and engagement with the material. The sentiments of many of the participants was summed up nicely by Erin who reflected on her lesson saying, "The time and energy invested is worth it because of student excitement and the value of what they learn through making. Students are not just learning content, but are also learning how to create, problem solve, and express themselves."

Discussion

Findings suggest that the participants were partially successful in turning their maker philosophies into actionable classroom practices. Twelve of 13 participants (92%) were in alignment on at least half of the Elements of Making considered in the analysis. Furthermore, the reflections of many participants suggested an awareness of missing elements and a desire for improvement.

The analysis also highlighted specific areas of overlap and disconnect between the philosophy sections and instructional practices of participants. Elements including the creation of a personally meaningful artifact, collaboration, and connection to STEM content were highly evident in both philosophies and showcase lessons of participants. However, some of the more nuanced aspects of these elements were missing.

Maker products inherently reflect something personal about the maker. Yet, an analysis of showcase lessons revealed that infusing projects with personal relevance was not an easy task for these participants. Including practices, like those of Layla and Nickie (such as asking students to reflect on, write about, and discuss their personal motivations with peers), as a regular part of classroom instruction may help students become more comfortable in identifying and finding inspiration in their interests.

Also, collaboration, as seen in the showcase lessons, was often bounded by the classroom. While most participants had students collaborating and working together, the notion of community rarely extended beyond the school walls. This need to expand and connect to the broader maker community was also missing from many reflections, suggesting that the participants were unaware of this gap.

The novice status of the majority of the participants may have contributed to this outcome. Since most of the participants were implementing the lessons in their student teaching semester, they may not have yet developed the professional connections, confidence, or planning skills required to orchestrate a public event or to connect with others in the community. Additionally, connecting with groups outside of the classroom is not a practice that is regularly modeled in the secondary STEM context.

Furthermore, only eight participants (62%) included instructional strategies to support the development of a maker mindset in their showcase lessons. This finding suggests that these teachers may assume their students will develop the skills of persistence, reflection, and failing forward as a natural byproduct of making. Thus, they did not build in activities that focused on these features. As with connecting to communities outside of the classroom, reflective activities that focus on process rather than product are uncommon in traditional secondary STEM classrooms.

The notion of iterative fabrication was absent from many philosophies and showcase lessons, which suggests a missed opportunity. Up until the point of this study, the majority of professional development offerings for participants had been a series of stand-alone workshops rather than an ongoing, related sequence. Thus, few opportunities arose for participants to engage in meaningful cycles of design, reflection, and redesign.

This make-and-take approach, along with the time restrictions in school instructional environments, may have led to the absence of iteration in the instructional practices of our participants. Given that iteration is a central feature of making, this finding indicates an area of needed growth for our program. Furthermore, this omission also highlights the tension of bringing making, with its informal roots, into a structured K-12 environment that is driven by content and standards (as also noted by Peppler et al., 2016).

Finally, the participants were teachers and they were makers. They saw teaching and making as deeply connected. They were motivated to engage in maker-centered instruction as a way to change the face of traditional STEM education and to empower their students to see themselves as creators and contributors to the world around them.

As the participants taught their students to make, they also made to teach. Many participants engaged in making artifacts to support their showcase lessons. For example, Mariana practiced her work with paper circuits, Adam spent hours laser-cutting car parts, and Kevin worked to develop skills for working with breadboards. In this way, making in classrooms can be educative for students while at the same time providing personally meaningful motivation for the teachers who educate them to design and build.

Limitations

No interview or observation data were included in the data corpus for this study. Instead, this study relied on a comparison of artifacts curated by the participants and presented as part of their Maker Showcase Portfolio, thus capturing a public face. Since the same curation process was employed for both the philosophy statement and the lesson, a public lens applies to both.

Additionally, while participants were likely to put their best foot forward, this curation provided a glimpse into what they valued and found most important to highlight. Some participants, like Layla, possibly did not enjoy writing. Thus, they may have provided a shorter philosophy section accompanied by richer lesson materials, leading to the impression of a low alignment between thoughts and actions that does not exist. Therefore, these factors must be considered as limitations of the data presented.

Furthermore, this study did not include an analysis of the data along content area lines and, therefore, did not fully address the ways in which discipline-specific context may influence teacher philosophies and lessons. For example, though 10 of the 13 teachers in the study taught either science or engineering courses, making as conceptualized by a biology teacher may differ from the notion as enacted by a chemistry or physics teacher. Thus, these subject specific nuances warrant future exploration and analysis.

Implications and Conclusion

This embedded case study uncovered various motivations for engaging with classroom making and maker-centered instruction and illustrated how STEM teachers in a maker-centered microcredentialing program take up and implement their maker philosophies in the secondary classroom setting. Findings suggest the need for additional research on models of maker-centered programs in teacher preparation as put forth by Cohen (2017). This study revealed that some entering the teaching profession are dissatisfied with the traditional ways in which STEM subjects are taught.

These findings suggest that STEM teacher educators should look for ways to connect STEM learning with innovative practices that promote a sense of agency and foster creativity. This study also suggests that teacher preparation programs and professional development providers must acknowledge and provide practical strategies for navigating restrictive educational environments in ways that fully allow for the implementation of participant maker philosophies. These strategies include the following:

- assisting teachers in the selection of learning goals that can be effectively addressed through maker-centered learning,
- helping teachers use making to address multiple learning goals as they explicitly highlight the science and engineering practices being used,
- supporting teachers with project planning and time management,
- providing teachers with specific tools and models to support the reflective practices that help students develop a maker mindset,
- including robust models for connecting outside of the classroom through school maker faires (Smith & Smith, 2016) or activities that involve community-centered making programs (Calabrese Barton & Tan, 2018), and
- providing teachers with opportunities to enact and reflect on their making philosophies as a vehicle for the refinement and revision of their instructional practices.

While this work acknowledges constraints in implementing maker-centered lessons in traditional educational settings, the findings also show the passion and engagement that making evokes. Like our participants, many STEM educators are eager to develop instructional strategies that will support students as they hone their problem-solving skills, build confidence in their abilities, and develop a sense of agency needed to tackle the complex problems of the future. In this way, making as an instructional practice is a promising frontier in STEM education that merits continued exploration.

References

Bevan, B. (2017). The promise and the promises of making in science education. *Studies in Science Education, 53*(1), 75–103. https://doi.org/10.1080/03057267.2016.1275380

Bowler, L. (2014). Creativity through "maker" experiences and design thinking in the education of librarians. *Knowledge Quest, 42*(5), 58-61.

Bullock, S. M., & Sator, A. J. (2015). Maker pedagogy and science teacher education. *Journal of the Canadian Association of Curriculum Studies, 13*(1), 60–87. https://jcacs.journals.yorku.ca/index.php/jcacs/article/viewFile/40246/36047

Calabrese Barton, A., & Tan, E. (2018). A longitudinal study of equity-oriented STEM-rich making among youth from historically marginalized communities. *American Education Research Journal, 55*(4), 761-800. https://doi.org/10.3102/0002831218758668

Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). *Maker-centered learning: Empowering young people to shape their worlds*. Jossey-Bass.

Cohen, J. (2017) Maker principles and technologies in teacher education: A national survey. *Journal of Technology in Teacher Education, 25*(1), 5-30.

Cohen, J., Jones, M., Smith, S., & Calandra, B. (2017). Makification: Towards a framework for leveraging the maker movement in formal education. *Journal of Educational Multimedia and Hypermedia*. *26*(3), 217-229.

DeCuir-Gunby, J. T., Marshall, P. L., & McCulloch, A. W. (2011). Developing and using a codebook for the analysis of interview data: An example from a professional development research project. *Field Methods, 23*(2), 136-155. https://doi.org/10.1177/1525822X10388468

Ellis, J., Wieselmann, J., Sivaraj, R., Roehrig, G., Dare, E., & Ring-Whalen, E. (2020). Toward a productive definition of technology in science and STEM education. *Contemporary Issues in Technology and Teacher Education, 20*(3). https://citejournal.org/volume-20/issue-3-20/science/toward-a-productive-definition-of-technology-in-science-and-stem-education

Fleiss, J. L., Levin, B., & Paik, M. C. (2003). The measurement of interrater agreement. In W.A. Shewart & S. S. Wilks (Eds.), *Statistical methods for rates and proportions* (3rd ed., pp. 598-626). John Wiley. https://doi.org/10.1002/0471445428.ch18

Hammerness, K., Darling-Hammond, L., & Bransford, J. (2005). How teachers learn and develop. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing teachers for a changing world: What teachers should learn and be able to do* (pp. 358-389). Jossey-Bass.

Harron, J. R**.**, & Hughes, J. E. (2018). Spacemakers: A leadership perspective on curriculum and the purpose of K-12 educational makerspaces. *Journal of Research on Technology in Education, 50*(3), 253-270. https://doi.org/10.1080/15391523.2018.1461038

Jones, S., & Woglom, J. F. (2017). *On mutant pedagogies: Seeking justice and drawing change in teacher education*. Springer.

Jones, W. M., Smith, S., & Cohen, J. (2017). Pre-service teachers' beliefs about using maker activities in formal k-12 educational settings: A multi-institutional study. *Journal of Research on Technology in Education 49*(3-4), 134–148. https://doi.org/10.1080/15391523.2017.1318097

Jordan, S., & Lande, M. (2016). Additive innovation in design thinking and making. *International Journal of Engineering Education, 32*(3), 1438-1444.

Marshall, J. A., & Harron, J. R. (2018). Making learners: A framework for evaluating making in STEM education. *Interdisciplinary Journal of Problem-Based Learning, 12*(2), 3.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research, 5*(1), 30–39. https://doi.org/10.7771/2157-9288.1099

Martinez, S. L., & Stager, G. (2013). *Invent to learn*. Constructing Modern Knowledge Press.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook*. Sage.

NGSS Lead States. (2013). N*ext generation science standards: For states, by states*. The National Academies Press.

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

Papert, S. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 1–11). Ablex.

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

Rodriguez, S., Allen, K, Harron, J., & Qadri, A. (2019). Making and the 5E Learning Cycle. *The Science Teacher*, 86(5), 48-55.

Rodriguez, S., Harron, J., Fletcher, S., & Spock, H. (2018). Elements of making: A framework to support making in the science classroom. *The Science Teacher, 85*(2). https://doi.org/10.2505/4/tst18_085_02_24

Silva, R. B., & Merkle, L. E. (2017). FabLearn, FabLab, MakerEd, experimental laboratories: Towards a discussion of a theory of maker education from a Brazilian perspective. In K. Y. Lim (Ed.), *Landscapes of participatory making, modding and hacking: Maker culture and makerspaces* (pp. 107–130). Cambridge Scholars Publishing.

Smith, W., & Smith, B. C. (2016). Bringing the maker movement to school. *Science and Children, 54*(1), 30-37.

Tofel-Grehl, C., Jex, E., Searle, K., Ball, D., Zhao, X., & Burnell, G. (2020). Electrifying: One teacher's discursive and instructional changes through engagement in e-textiles to teach science content. *Contemporary Issues in Technology and Teacher Education, 20*(2). https://citejournal.org/volume-20/issue-2-20/science/electrifying-one-teachers-discursive-and-instructional-changes-through-engagement-in-e-textiles-to-teach-science-content

Vossoughi, S., & Bevan, B. (2014). *Making and tinkering: A review of the literature*. National Research Council Committee on Out of School Time STEM. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_089888.pdf

Wilson, J., & Gobeil, M. (2017). Guitars and makerspace: Examining the experience of First Nation students. *Canadian Journal of Learning and Technology, 43*(12), 1–16.

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). Sage.

Appendix A
Six Elements of Making in the STEM Classroom

Makers create original, personally meaningful products.

Maker-centered instruction promotes self-expression and empowerment that is driven by personal cares, creativity, and learning by doing (Martinez & Stager, 2013). Through the act of design and reflection, students are encouraged to identify their own interests and passions, develop agency in their own learning, and find inspiration for the creation of personally meaningful products (Papert, 1991).

Makers engage in iterative design and fabrication.

Making is an iterative process that allows participants to select and use a wide variety of materials and both high and low-tech tools. Thus, maker-centered instruction fosters a design and fabrication process that may use crafting materials, hand and power tools, electronics, soldering, 3-D printers, laser cutters, and more (Marshall & Harron, 2018). Like the engineering and design thinking process, maker-centered instruction provides opportunities for students to create prototypes, test their outcomes, seek feedback, and engage in continuous revision and refinement (Jordan & Laude, 2016).

Makers demonstrate characteristics of a maker mindset.

A maker mindset is playful and growth-oriented while promoting effort and persistence (Martin, 2015). Successful maker-centered instruction helps students develop a failure-positive attitude and supports them in viewing setbacks as a chance to rethink and revise their work. Maker-centered instruction promotes collaboration and flexible thinking along with a sense of playfulness and enjoyment in learning.

Makers collaborate and connect with community.

The maker community is characterized as "inclusive, embracing, and welcoming to all those who make" (Clapp et al., 2016, p. 5). To support this notion, maker-centered instruction provides opportunities for students to collaborate on ideas, tools, and designs, with makers from other vibrant communities through both in person and online interactions. Maker-centered instruction fosters inclusivity and community building.

Makers present work publicly.

The public sharing of work allows makers to contribute and draw upon innovative ideas and products of the broader maker community. Without this reciprocal relationship, the maker community and the advances it fosters would cease to exist. Therefore, maker-centered instruction includes practices that seek out forums for students to present their work publicly and showcase their work both inside and outside of school contexts (Smith & Smith, 2016).

Makers use Science, Technology, Engineering, and Math (STEM).

Science, mathematics, and engineering practices are used by makers when they formulate questions, design models, make measurements, test their hypotheses or products, and communicate information. Due to the transdisciplinary nature of design and making, many of these practices may emerge intuitively rather than being explicitly articulated when enacted in informal making settings. As such, maker-centered instruction aims to bring the core ideas and disciplinary practices of STEM to the forefront (Bevan, 2017).

Appendix B
Comparison of Philosophy Excerpts and Showcase Lessons With Regard to Elements of Classroom Making for a Single Participant.

Elements of Making	Esha's Philosophy Excerpts	Esha's Showcase Lesson
Create personally meaningful products	**Present** "I think it would be cool if I was to ask students to make anything they would like to make. After that, I would give them a set of materials to choose from."	**Present** Students use recipes to make soaps and personalize according to preferences for scent, color, etc. Students get to modify a template to make a soap dish holder.
Engage in iterative design and fabrication	**Present** "[In making] something that can always be adjusted to be better than what it already is… it's a work in progress." "Maker education emphasizes design thinking."	**Present** Students follow recipe and templates but are able to iterate and adjust/modify if they want. Some students did not get to fabricate soap dish holder on their own due to time constraints.
Demonstrate characteristics of a maker mindset	**Present** "Making always involves something that you are passionate about" "Making can be anything, you just have to think of something you want to make and figure out how it can be done."	**Present** Students are introduced to making through the teacher showing herself as a maker and sharing her successes and challenges as well as her own inspirations. Students are asked what making means to them and to reflect on things they had made in the past.
Collaborate and connect with community	**Present** "One of the most important aspects of maker education is the idea of collaboration. If educators work together to help students become active learners, then teaching students in a constructive manner becomes much easier."	**Absent** While students have opportunity to discuss and interact throughout the soap making process, it is primarily an individual activity with no strategies in place to support collaboration.
Present work publicly	**Absent** Not mentioned in participant's philosophy statement.	**Present** Students present their products to outside community members at the end of the lesson. Did not seek extensive feedback for iteration.
Use STEM	**Present** "I would like to be able to get those students to look up scientists and build something that the scientist discovered or thought they discovered."	**Present** Students create their own process notes that show stages of chemical reactions and processes. Standards and content concepts are deeply explored. Students create a visual diagram of chemical reactions during project.