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Designing (and) Making Teachers: Using Design to Investigate the Impact of Maker-Based Education Training on Pre-service STEM Teachers*

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This qualitative study examined how a maker-based education workshop affected 20 pre-service STEM teachers' views of the lesson planning process. Design is used as both an epistemological link between making and teaching practices as well as an analytical lens through which lesson planning could be interpreted and understood. The findings of this study suggest that pre-service teachers who have been introduced to maker-based principles and practices are able to imagine a lesson planning process that is more student-centered and active than the kind which they normally utilize. While there was a contrast between the content of making-based and traditional lesson planning processes, the pre-service teachers' designs of these processes were largely the same: linear, verbal, and only occasionally reflective or iterative. These characteristics match those of novice designers.

Keywords: maker-based education; teacher training; professional development; design epistemology

1. Introduction

Learning Sciences research has provided compelling evidence that student-centered, constructivist-based, and problem-driven pedagogies – key pillars of progressive educational philosophy – are also the basis for effective teaching [1–4]. Introducing and sustaining these practices in schools, however, has proven challenging; institutions have been reticent to reform the structures and processes that reinforce the instructionist paradigm which has dominated formal education since the late 19th-century [5, 6]. The social phenomenon known as the Maker Movement has created renewed interest in bringing the knowledge, skills, and attitudes associated with progressive education into formal learning institutions [7, 8], with significant support coming from Science, Technology, Engineering and Mathematics (STEM) disciplines. Formalized maker-based education efforts often focus on K-12 students and community members through high-tech workshops, often known as makerspaces, and the training and use of digital fabrication tools like 3D printers, laser cutters, and CNC mills. These efforts also frequently emphasize collaboration, creative problem-solving, iteration, agency, and empathy [7].

Yet even educators who are enthusiastic about introducing making [7, 8] into their classes face the challenge of learning new skills, developing new types of curricula, and reorienting themselves to fundamentally different standards of classroom behavior, pedagogy, and assessment. Before introducing making into their classrooms and curricula, it may be helpful for teachers to first identify and connect with their own professional practices, which, like making, include exploration, design, inquiry, and iteration [8, 34].

This study examined how pre-service teachers' lesson planning processes changed after a short-form training session focused on maker-based education. Design was utilized as a lens through which these lesson plan processes could be interpreted and understood.

2. Supporting STEM, but Teaching More: The Conflicted Rhetoric of Maker-Based Education

The notion of "making" as a social and educational phenomenon is simultaneously very old and very new [9]. Dougherty asserts that the Maker Movement "has come about in part because of people's need to engage passionately with objects in ways that make them more than just consumers" [10, p. 12]. He argues that this kind of engagement has its

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roots deep in human history, recently becoming enhanced by Internet communication. By sharing designs and processes for repurposing existing technologies, people can "hack" the world around them. Additionally, the decreasing costs of digital fabrication equipment has encouraged the development of open-source technologies, which are explicitly designed to be hacked and used in ways the original creators could not have foreseen [11].

The result of these developments has been the emergence of a group of individuals who were driven by their own interests to acquire knowledge and skills from quite a range of disciplines including knitting, molecular gastronomy, sculpture, material science, electrical engineering, leatherworking, robotics, and graphic design [12]. These self-identified "makers" have also channeled their passion towards helping solve both wide-spread social issues and problems specific to their local communities. It is no wonder that when policymakers and educators heard stories like that of a high schooler creating a 3D-printed prosthetic hand for their teacher [13] or a middle school girl who became a YouTube celebrity based on her videos about hands-on science activities [14], a concerted effort to bring the Maker Movement into education began. The first wave of national attention peaked in 2014 when President Barack Obama hosted the first White House Maker Faire, which featured a large number of young Makers and focused heavily on the educational potential of making [15].

Martinez and Stager [8] present a different historical narrative, suggesting that considerations of formal education were actually critical to the Maker Movement's birth and development. They argue that the Maker Movement was an outgrowth of several cultural strands, including the progressive education movement, the roots of which they trace back to the 18th century, but started in earnest with philosopher John Dewey in the early 1900s [16]. Dewey rejected many of the fundamental assumptions underlying formal education, such as the notion that knowledge was akin to a static object that could be given from teachers to students. His critiques laid the groundwork for the research of Vygotsky [8], Piaget [3, 17], and Papert [5, 18], who collectively formulated a vision of learning centered on the mental, social, and physical construction of knowledge. Martinez and Stager [7] credit Papert for showing how computers could be transformative tools for constructivist learning, a move that predated the Maker Movement's transition into education by roughly 30 years.

By aligning making with increased student engagement and competency in STEM [19] , both narratives have helped the Maker Movement gain traction in education. Yet, the learning outcomes that Maker educators most frequently promote generally fall outside the traditional bounds of STEM disciplines. Martin [7] suggests that students who develop a "Maker Mindset" are playful, asset/growth-oriented, failure-positive, and collaborative: traits that may be helpful for the next generation of scientists and engineers, but also for students with a wide range other career trajectories. He also raises concerns about the fate of school makerspaces, the collaborative, shared use workshops that provide students with access to digital and traditional fabrication tools. Martin suggests that, if makerspaces are valued solely for the technical equipment they contain and not for the Maker Mindset qualities they can foster, then they will suffer the same fate as the now-defunct computer labs of the last generation.

While efforts to institutionalize maker-based education have been bolstered by calls for more student participation in STEM [20, 21], it seems that its advocates are not strictly concerned with the standard canon of conceptual scientific knowledge, mathematical problem-solving methods, or engineering analysis [22–24]. This disconnect suggests that another perspective might be useful in understanding the relationship between maker-based education and the STEM disciplines. To that end, we turn to the topic of design.

3. Making (is actually) a Case for Design Education

The title of the compilation *Design, Make, Play: Growing the next generation of STEM Innovators* [25] nicely captures the tension highlighted in the previous section. While advocates of making and design in education are vocal about its potential to create a generation of tech-savvy innovators [26], they also seem interested in shifting the emphasis of formal education onto fundamentally different types of learning. Consider the following excerpt regarding the importance of design from Honey and Kanter:

> ". . . design is a powerful vehicle for teaching science, technology, engineering, and math (STEM) content in an integrated and inspiring way. Through the design process, one learns how to identify a problem or need, how to consider options and constraints, and how to plan, model, test, and iterate solutions, rendering higher-order thinking skills tangible and visible" [25, p. 3].

While design is clearly a valuable "vehicle" for delivering STEM content, often by providing authentic and meaningful contexts for inquiry, the same logic could be utilized outside the context of STEM. The skills mentioned (planning, modeling, testing, etc.) are applicable to a wide range of non-

Table 1. A theoretical conception of the sciences, humanities, and design as distinct dimensions of education. (Adapted from Cross [27])

	Sciences	**Design**	**Humanities**
Phenomenon of Study	The natural world	The artificial world	Human experience
Methods of Inquiry	Controlled experiment, classification, analysis	Modelling, Pattern-formation, Synthesis	Analogy, metaphor, evaluation
Values	Objectivity, rationality, neutrality, concern for 'truth'	Practicality, ingenuity, empathy, concern for 'appropriateness'	Subjectivity, imagination, commitment, concern for 'justice'
Mode of Reasoning	Deductive	Abductive/productive	Inductive

STEM contexts and professions, such as policy-making, city planning, or marketing. Is it possible that these efforts are actually pointing to a much larger educational reform?

Cross identifies a related issue in his paper *Designerly Ways of Knowing* [27], which presents a compelling argument for design as being distinct from the recognized "academic cultures" of the sciences and humanities (see Table 1). He observes that design has historically been associated with crafts and manual skills, warranting little regard in the realm of formal education. Upon closer inspection, Cross finds that design connotes a world view and epistemology constituting a third independent culture, one which focuses on the built environment, the active generation of new objects and ideas, and the ability to address ill-defined problems with incomplete information. These qualities inform, in part, a designerly way of knowing.

At first glance, these characteristics may appear to reside squarely within the domain of engineering; yet, artists are intimately in touch with the built world, the main task of a writer is to generate new ideas, and teachers are constantly addressing ill-defined problems with incomplete information. None of these are STEM-based professions, yet they all seem to benefit from a design perspective. It is worth acknowledging that, within the STEM disciplines, design plays a special role in engineering. A number of scholars, particularly in the field of engineering education, have made considerable contributions to our understanding of different design processes [28–30] and how they are learned [31, 32].

Proponents of maker-based education advocate for its design focus while simultaneously touting its ability to improve student performance in STEM fields. Since traditional standardized metrics (e.g., test scores) will not capture outcomes like persistence, collaboration, and self-efficacy, an eventual reckoning may be on the horizon. Educators may not be explicitly addressing the incompleteness of the "two cultures" model, but interest in making, as well as STEM-to-STEAM programs [33] suggests that some educators may think something is missing. Design and making have started to appear in teacher training programs [34, 35]. Maker-based educational training provides unique opportunities to evaluate how pre-service teachers and their trainers might change their own practices to better align with new educational paradigms.

4. Teaching as Design

One of the obstacles for achieving sustained progressive education reform resides in the gap between the ingrained traditional knowledge and practices that educators are familiar with and the new ones they wish to develop in students [36]. While studies focus on the teaching *of* design as well as making-based educational content in informal settings, few if any have looked at how making and design practices are reflected in the work activities of teachers.

It is worth noting that this mirroring of professional engineering practice and course content is a special case and does not make sense for all disciplines or professional arenas. The ways teachers teach does not necessarily need to embody the content they are teaching. Presenting a historical narrative does not necessarily require the skills of a historian, nor does the teaching of neurology (hopefully) utilize the actual techniques of a brain surgeon, though familiarity with these skills is helpful. Instead, the authors posit that design is uniquely situated; teachers are being asked to deliver content pertaining to design-based skills and processes while also being in a role that would benefit from the enactment of those same skills and processes.

The notion of teaching as a form of design, while not new, is relatively unexplored within academic literature. Dinham [37] first suggests that there are strong parallels between the roles of designers and teachers generally, though mainly focuses on understanding instructors of design content who work in undergraduate architecture studios. Likewise, Goodyear [38] offers a thorough account of higher education teaching from the perspective of design, focusing on the forces that are currently at play in the large research university domain.

In none of these cases are the basic tasks and roles of a K-12 teacher addressed through the lens of design. Jordan [34] took such an approach by examining how pre-service teachers fared in an undergraduate pedagogy course that was based on designing learning environments and technologies. Rather than explicitly referring to teaching as a design process, the students were asked to periodically draw out the steps they went through to complete their project. In the end, they had created a diverse set of highly complex design maps perhaps not dissimilar from those of professional designers [39]. Jordan [34] provided a major impetus for this current study, which is smaller in scope but utilized a related methodology of looking for evidence of design in teacher planning processes.

5. Research Design

The central question of this study is: How might a class-length introductory maker-based education workshop change the form and content of pre-service teacher's design processes to create lesson plans for their classrooms?

5.1 Context

The data used in this study were collected during one class period of a semester-long Science Teaching Methods course at a large research university in the Southwest United States. The course was intended for pre-service teachers (undergraduate education majors) who wanted to gain more advanced knowledge pertaining to the teaching of core concepts and processes related to science and engineering, specifically for the K-8 grade range. Students in the course were introduced to key research-based learning theories and, through multiple student teaching opportunities, were encouraged to translate their conceptual understanding of learning theories into practice in their future classroom contexts. As an example of this course's efforts to adopt more progressive, student-centered teaching strategies, it made heavy use of the inquiry-based lesson plan framework [40].

Approximately 10 weeks into the semester, the course instructor permitted the first author to lead a 75-minute, hands-on workshop that provided a short overview of the Maker Movement and one primary tool used to support making in K-12 classrooms (see Fig. 1). This tool, known as the Makey Makey, is a simple electronic microcontroller that will effectively turn any conductive object into a computer keyboard input. The pre-service teachers worked in groups of 2-3 and used a range of materials to devise creative ways to use the microcontroller as an input device for simple games and simulations running on their laptops. Approximately 15 minutes of didactic presentation was given. The remainder of the instructor's time was spent walking between the groups of students to make sure they were not facing significant technical difficulties (allowing students to become somewhat confused or frustrated is part of a maker educator strategy to encourage persistence and grit), asking questions that provoked reflection, and improving the quality of group collaboration.

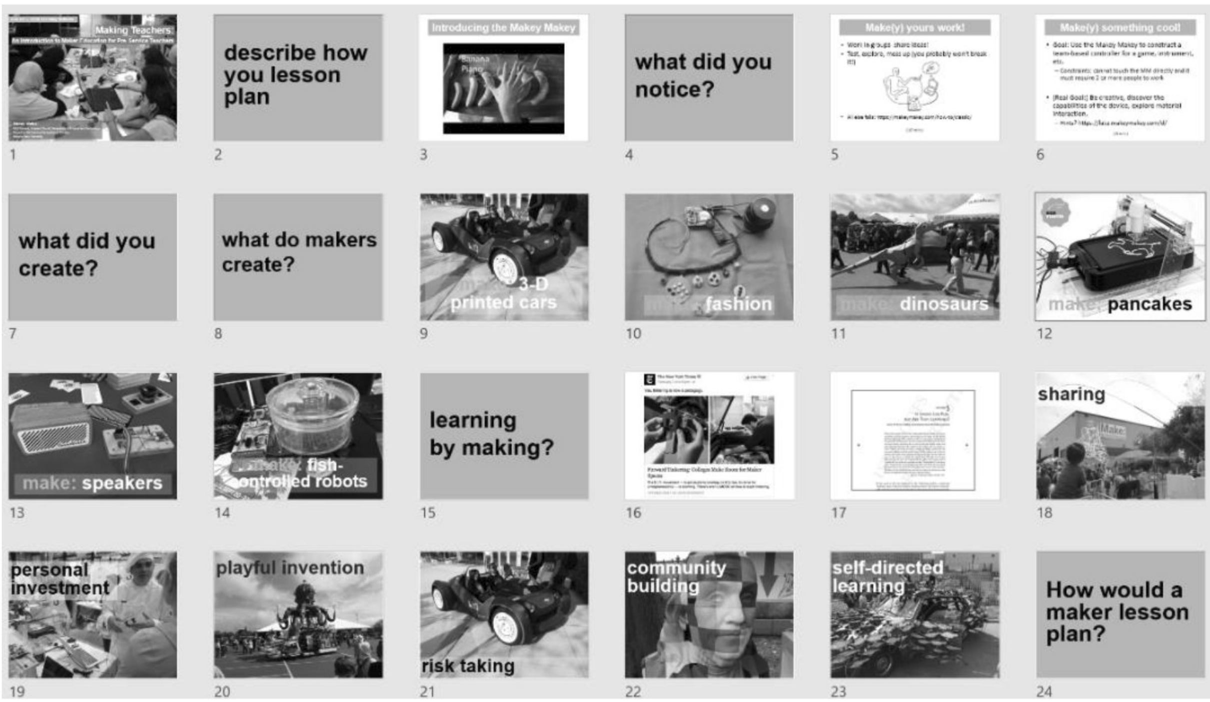

Fig. 1. Thumbnail overview of maker-based education workshop presentation. (Selected slides courtesy of Lande, M. and Jordan, S.).

5.2 Method

This research was conducted as a pilot study for the first phase of a larger design-based research study [41]. A maker-based education teacher training workshop was designed and administered in its authentic context in concert with teacher trainers. Although the first author participated as both educator and researcher, these roles were not logistically difficult to separate, since data collection occurred before and after the workshop in a pre-post fashion and the time during the workshop was spent focusing on engagement with the participants during the intervention.

5.3 Participants

Of the 23 pre-service teachers participated in this study, three identified as male and 20 identified as female. The range of reported ages spanned from 20 to 48. The breakdown of self-reported ethnicity is as follows: 1 Asian, 2 Hispanic, 16 White/Caucasian, and 4 unreported. Written consent to use the findings derived from participant data in published material was secured following the workshop session through IRB-approved protocols.

5.4 Data

The sources of data for this study were written participant descriptions of their lesson plan design process pre- and post-intervention. Students were given approximately 5 minutes at the beginning of the workshop to describe how they normally lesson plan. To avoid biasing participant responses, the words “design” and “depict” were intentionally not included on this slide, though the instructor verbally suggested during this time that participants could draw a picture or diagram if they would like.

At the end of the workshop, they were given another five minutes to describe how a maker would design a lesson plan (see Table 2). This wording was also used specifically; given that the participants were just introduced to the idea of making and may not feel as if they could credibly imagine themselves as maker educators after a short training, an attempt to side-step the issue was made by asking the question about a hypothetical “third-party” maker.

5.5 Analysis Methods

The data were analyzed in two ways: First, the process descriptions were analyzed on a syntactic level, looking at the word choice and the relative frequency of certain words. For this analysis, data from participants was considered in the aggregate and collective comparisons were made between pre- and post- descriptions. Second, the process descriptions were analyzed on an individual participant basis, specifically looking for changes between each person’s pre- and post-workshop descriptions. Memos and notes from this second analysis served as the basis for the thematic findings [42, 43]. A process map analysis [44] was under consideration as a way to better understand how teachers conceived of lesson planning, but no participants utilized visual mapping to describe their process.

6. Results

Of 23 participants, 20 provided analyzable data for the study. (Two did not finish their post-workshop process descriptions and the other was not legible.) Data were analyzed by word frequency to see what sorts of words were used and how often [45]. The following word clouds represent the aggregated vocabulary used in the pre- and post- workshop descriptions (see Fig. 2) with word sizing representing relative frequency. The pre-engagement word cloud is based on their prior knowledge including what they learned in this class, and the post-engagement word cloud is their perspective on how one would design a lesson plan from a making perspective. (See Appendix A for pre- and post-engagement charts listing the ten most frequently mentioned words along with relative frequencies.)

When analyzing the data, certain words, such as “student” and “students”, were lemmatized (i.e., collapsed into one category for counting purposes). Also, the same word used multiple times in one description was not counted, as the point was to understand the overall frequency within the class, not within the individual. Impersonal pronouns, conjunctions, and articles were all excluded.

7. Findings

7.1 Pre-service Teachers think about their Practice like Novice Designers

In comparing participants’ lesson planning process descriptions from before and after the workshop, no significant changes in answer form were observed. The processes were consistently linear in nature,

Table 2. Example of pre- and post-intervention participant lesson plan process descriptions written by participants

Pre-Engagement:	Post-Engagement:
“First you come across a really cool idea or project you’d like to teach. Then you take that idea and see if it fits standard in your subject. Then you modify in any way you need to for your students. Then you teach.”	“They would find a passion and take risks to create a new lesson. They would think outside the box in order to get students to make. Lesson planning would mean less “planning” and more allowing students to explore.”

Fig. 2. Word clouds depicting frequency of word usage via relative size in pre- (left) and post- (right) intervention lesson plan process descriptions.

formatted verbally with no pictures or symbols, and made little reference to iteration or reflection. Some participants made bulleted lists, though most were written out in a narrative paragraph. Out of all 20 pre- and 20 post-descriptions, only one contained the word "revise" and another described improving a lesson for a following class.

This finding strongly suggests that pre-service teachers think of their lesson planning design process as design novices would with no formal training in either design thinking or engineering design process [32]. This conclusion is unsurprising, as that is precisely what they are. It also indicates that a brief introduction to maker-based education, which only obliquely references design considerations, has no observable impact on how pre-service teachers engage in the lesson planning design process. This finding is also unsurprising, as teachers are routinely presented with content that is expected to be deployed for the benefit of their students; rarely, if ever, are they prompted to consider how such content might improve their own practice.

7.2 Standards come before Students

Although the number of participants who used the word "students" remained almost constant between pre- and post- descriptions (13 participants before, 14 after), the word "standards" was use 15 times in the pre-workshop descriptions, making it the most common word mentioned. Given that this course was purported to teach student-centered and inquiry-driven teaching methods and practices, it is striking to see such a dominant focus on standards. Students were still mentioned frequently but were not the central priority: perhaps an accurate reflection of the tensions present in the modern classroom.

7.3 Teaching is about what Teachers "Teach, Write, Find", not what Students "Create, Explore, Question"

There was a notable shift in the types of verbs participants used – and who was referred to in the subject of the verb – before and after the workshop. When describing their normal lesson planning process, teachers described needing to "find" activities that would meet a standard, "write" out what needed to be learned, and then "teach" it. This stands in contrast to their conception of a making-based lesson plan which provides students with opportunities to "create", "explore", and "question." This observation is striking specifically because the overarching pedagogy of the Science Teaching Methods course was based on student-driven inquiry and exploration. Despite this explicit focus, a hypothetical making-based lesson appears more able to honor this ethos, perhaps because of the perceived lack of accountability that making has to standards.

7.4 Making is "Random"

A minor finding from the study concerns the frequency of the word "random" in the post-workshop descriptions. Teachers often stated that a maker might provide students with "random materials" during a lesson. While the instructor's intent was to convey the eclectic nature of making, which often involves utilizing objects in unexpected ways[1], the intentionality of the materials selection was not

[1] During the workshop, one group of teachers embodied this quality in a surprising way. Rather than using the scissors as tools for constructing a Makey Makey controller, they hooked alligator clips to their sides and used them as controllers. At one point, they had five pairs in a row, making what appeared to be a teacher s nightmare: a scissor piano keyboard.

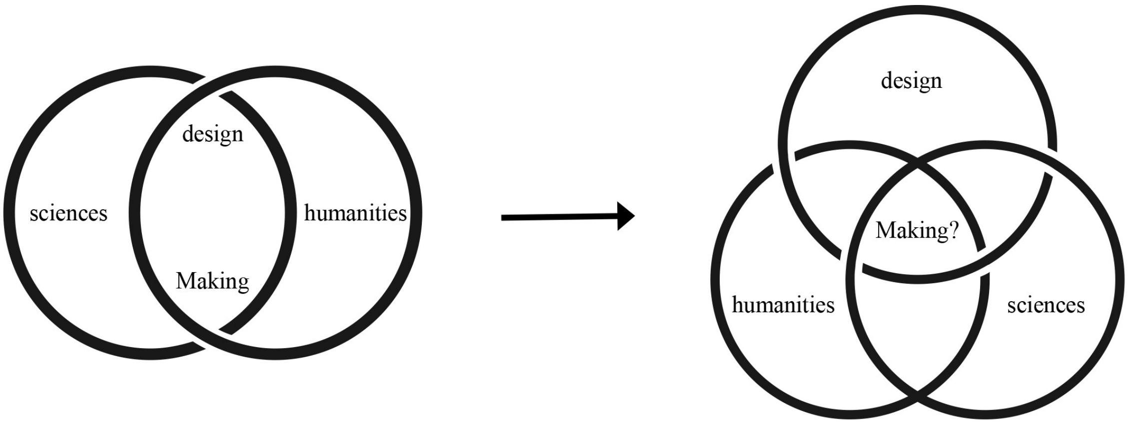

Fig. 3. Conceptualizing the transition from a two-culture to three-culture educational paradigm (based on Cross [27]).

explicitly discussed with participants. By providing insight into how making may be initially perceived by educators, this finding also serves as a useful critique of the presentation design choices during this workshop.

8. Discussion

8.1 Exploring Tensions between Making and Standards

As noted earlier, the word "standards" was used 15 times on the pre-workshop descriptions. After the workshop, the word only appeared on three participant descriptions. The message sent through the introduction to maker-based education, intentional or not, was that making and standards do not mix – or at least, that standards are not a high priority for educators using making in the classroom. This may be accurate, though the fact that this came across so strongly in such a short timeframe gives reason to pause and reflect. What is the appropriate relationship between maker-based education efforts and standards? It seems obvious that not having any structures in place which guide and organize learning would be ill-advised; yet, one of the defining features of a grassroots maker is their passion-driven, self-regulated learning [8, 23]. So, how do educators maintain some semblance of curricular order, while also providing students with the freedom to generate and explore their own independent interests? Can this be done consistently within the bounds of a formal educational system? This may be one of the critical issues to be resolved if maker-based education efforts wish to be successful at cultivating the signature passion of grassroots makers in students, in both informal and formal settings. There may be a mismatch of desired goals and outcomes that presents incompatibilities with making in formal education settings in particular [8, 10, 12].

8.2 Maker-based Education as an Entry Point for Teaching Teachers "The Third Culture"

If we consider Cross's claim that design should be considered a new dimension to general education in line with the sciences and humanities, it might be the case that making could help introduce the idea to teachers and administrators. Many maker activities are often low-pressure and have low-barriers to entry [4]. They also have a design component, situating them as the perfect entry point to start a conversation (see Fig. 3). The notion that there are deep connections between designing physical objects, like Makey Makey controllers, and intangible systems, like lesson plans, is not obvious. Using fun and accessible activities that also can be make more complex would allow teachers to get comfortable with simple design problems which can be ramped up to be more ill-defined, transferred to different contexts, and complicated with conflicting information and stakeholder priorities. Maker-based education may also be useful for integrating other dimensions of design that could inform not only teachers' engineering content knowledge, but also their own teaching practice. For example, Schon's notion of the reflective practitioner [45] could be introduced and explored via teachers' reflections on their experiences while engaged in making.

9. Conclusions

The findings of this study suggest that teachers who have been introduced to making principles and practices are able to imagine a lesson planning process that is more student-centered and active than the kind which they normally utilize. While there may be a contrast between the content of maker-based and inquiry-based lesson planning processes, the teachers' designs of these plans were largely the same: linear, verbal, and only occasionally reflective or iterative. These characteristics, unsurprisingly, match those of novice designers.

These findings should not be taken as generalizable to a larger population of pre-service teachers or even a detailed picture of these specific teachers' thinking regarding lesson planning. Nevertheless, they are evocative of other questions: How might educators benefit from being trained to see themselves as designers of learning experiences? Would such training be particularly useful for the development of maker-based education practices? What drawbacks or unintended consequences are there to introducing such elements into classrooms?

Further, more questions arise when seeking ways to improve the study's design and achieve more robust and generalizable conclusions. How would the results of this study change after a two-hour workshop? A week? A full maker-based education training program? Is there an element of tacit or cultural knowledge that does not get passed on in short-form engagements that might be instilled through a longer program? What differences arise when working with in-service teachers or experienced teachers from secondary or higher education? These questions would be excellent starting points for continuing this line of research in the future.

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Appendix A

Pre/Post-Engagement Comparison of the 10 Most Frequently Used Words

Pre-Engagement		**Post-Engagement**	
Most frequent words with % of total (N = 299)		**Most frequent words with % of total (N = 240)**	
standard(s)	5.0%	students	5.8%
student(s)	4.4%	create	3.8%
activity/ies	4.0%	materials	3.3%
find	3.0%	maker	2.1%
think	2.7%	something	1.7%
write	2.3%	random	1.7%
teach	2.3%	explore	1.7%
I	1.7%	build	1.7%
objectives	1.3%	question	1.3%
lesson	1.3%	problem	1.3%

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