MAKER EDUCATION AND STEM FIELD RESILIENCE FOR K-5 LOW-INCOME GIRLS

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Abstract

The Maker Movement has grown in its scope in terms of number and diversity over the past decade. Making relies on experiential learning and self-driven inquiries, and it typically involves the integration of digital technologies such as 3D printers to produce physical artifacts. Educators of Science, Technology, Engineering, and Math (STEM) have begun to incorporate Making into curricula for students to make concepts more tangible and relatable. Studies have previously shown that Making can also have long-term effects on young students, such as increased interest in the STEM field and higher levels of self-efficacy and resiliency in the students. In the context of the gender gap in STEM that has prevailed for centuries, Making at a young age could be a way to bring more women into STEM careers. However, there are many considerations that need to be made when deciding whether Making should be incorporated into formal education or informal education. A literature review was conducted to propose recommendations for the best course of action for implementing Maker education and determine criteria that can be used to standardize Maker education programs. While incorporating Maker education into formal educational settings could increase accessibility and interest in STEM, many schools lack the funding, resources, and human capital to properly implement Making into the standard curriculum. The existing literature suggests that Maker education programs can be most effective when implemented into informal educational programs, provided that they are made accessible to and specifically accommodate low-income students.

Keywords: Maker Movement, STEM education, formal education, informal education, after-school, extracurricular, self-efficacy, female youth, low-income students

Introduction

In recent discussions about Maker education programs for K-5 students, one point of debate has been whether they belong in formal school settings or informal extracurricular settings. This discussion is particularly important because Maker education programs can have a positive effect on a student's sense of self-efficacy and confidence to study and work in fields of Science, Technology, Engineering, and Mathematics (STEM). Self-efficacy and resilience, while distinct from one another, both relate to "one's ability to persevere in the face of difficulty" (Djourova et al., 2019, p. 259). The main distinction is that self-efficacy refers to the accomplishment of future goals and tasks, while resilience is a "dynamic quality" (p. 259) that refers to the ability to adapt to change, withstand challenges, and recover from adversity (Djourova et al., 2019). While quantitative measures of resilience will not be used in this thesis, it is nonetheless an important component to consider.

Much of a child's socialization occurs in schools, where they are influenced by educators and peers alike (Raabe et al., 2019). Thus, the environment in which learning takes place can have a significant impact on a student's experience and self outlook. Furthermore, a student's preference of school subjects can often predetermine the careers they choose to pursue (Raabe et al., 2019). It would be a disservice to female students if they were discouraged from having a preference for STEM subjects at an early age, as it could have long-term implications on perpetuating the gender gap in socioeconomic status (Raabe et al., 2019). By the same token, making STEM accessible to students of lower socioeconomic status can provide them with the resources and opportunities to break the cycle of poverty.

One argument, as presented by Nemorin (2016), posits that Maker pedagogy should be incorporated into formal education and school settings in order to make the greatest impact and reach the highest number of students. In formal education, however, the principles of Making are limited by the standards imposed by the state and the school district. Another argument, as presented by Hsu et al. (2020), posits that the integrity of Maker pedagogy can best be maintained in informal education outside of school settings. This is because students are better able to explore their own interests in a low-stakes environment, and being in an extracurricular Maker education program improves students' opinions about STEM and confidence in themselves according to the existing literature surrounding Maker education (Voussoughi et al., 2016).

While I agree that incorporating Maker education into classrooms could increase accessibility and interest in STEM, I would also point out that many schools lack the funding, resources, and human capital to properly implement Making into the standard curriculum. While informal educational programs also require a source of funding, they do not have the responsibility of allocating these funds to address a wide variety of needs outside of the program itself. Meanwhile, schools have to consider supporting many other departmental needs outside of just Maker education.

Additionally, most state standards do not include competency in Making. States that are following the Next Generation Science Standards (NGSS) do include standards in relation to engineering, but there are no nationwide sanctions to obligate educators to provide quality Maker pedagogy in formal education. Therefore, in this paper, I argue that Maker education programs can be most effective when implemented in extracurricular programs, provided that they are made accessible to and specifically accommodate female low-income students. While informal educational programs only have the resources to serve a small number of students, targeting this demographic could bring Making to students that have the least access to this type of programming and the greatest need for it.

The following thesis is a literature review of peer reviewed studies conducted in the fields of Maker education and, more broadly, STEM education. In this thesis, I will begin by providing context and background information on the Maker Movement, the gender gap in STEM, and the educational disparities that exist for students of lower socioeconomic status. Next, I will introduce two frameworks by which Maker education programs can be evaluated and argue for which framework should be used. Then I will compare the benefits and limitations of implementing Making into formal educational settings and informal educational settings, as well as other program logistics that must be considered. I will conclude this thesis with a proposal for a Maker education program based on the recommendations made by the existing literature.

Background of Making and the Maker Movement

Making is based in Constructionism, where the learning process is centered around problem solving and "production-based experiences" (Halverson & Sheridan, 2014, p. 497). Bevan (2011) posits that "materials-based investigations" (p. 75), as well as experiential learning and self-driven inquiries are central to Making, demonstrating a departure from focusing solely on conceptual learning. Making typically involves the integration of digital technologies such as 3D printers, though projects can also be virtual or utilize non-digital technologies such as sewing (Bevan 2011). Although Making often incorporates technology, these tools are not the emphasis, but rather the vessels by which Makers can hone their creative processes and develop physical artifacts (Bevan 2011). Artifacts are the products of Making activities. Halverson and Sheridan (2014) define the Maker Movement as "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" (p. 496). This definition highlights that a key part of the culture surrounding the Maker Movement is sharing one's artifacts as well as the processes that were involved in the artifacts' production with fellow Makers in the community.

Positionality Statement

I became invested in studying and teaching Maker pedagogy because of my involvement with MakerGirl, a non-profit initiative with a goal to bridge the gender gap in STEM by educating girls ages 7-14 about STEM subjects through 3D printing workshops and long term project-based programming. In my three years of involvement with MakerGirl, I helped establish the UT-Austin MakerGirl Academy and have taught over 115 workshops. MakerGirl emphasizes outreach to students of racial and ethnic minorities, as well as students that qualify for free or reduced school lunch due to their socioeconomic status. As an undergraduate double major in Public Health and Linguistics, I had little knowledge of the field of educational research and literature prior to writing this thesis. However, my experience in my two majors opened my eyes to the significant implications of disparities in the quality of education for people of different socioeconomic statuses that begin at a young age. Even before I began pursuing my undergraduate degrees, I was socialized in an environment that favored male students in the STEM field and I still deeply empathize with other girls and young women who face the same circumstances today.

MakerGirl receives the majority of its funding from corporate sponsors, generous private donors, and grants in order to offer its programming at a free or reduced cost to all students. While MakerGirl technically functions as an informal educational program after school and throughout the summer, occasionally MakerGirl will partner with individual teachers or schools and offer its programming during the school day in the form of a guest presentation. In response to the COVID-19 pandemic, MakerGirl created virtual curricula and delivered its workshops to students via Zoom. My experience with MakerGirl gives me insight into how informal educational programs function, though this also influences my favorable view of implementing Maker education into informal educational settings.

A Firsthand Account of the Positive Impact of Maker Education

By far, my favorite teaching moment during my time volunteering with MakerGirl was with a student that I will refer to as Anna in this brief anecdote. Her name has been changed in order to protect her privacy. Anna was about 8 years old when she began attending MakerGirl 3D printing workshops. She joined a virtual five-day independent inquiry program that allowed her to create her own project throughout the week and present it to her peers and family members on the final day. During the first day of the program, Anna was so shy and intimidated by her peers that she would not turn on her camera or unmute herself to speak on the video conference. Because the program was completely virtual, it was a challenge for me to gain insight on her progress, engagement, and overall feelings. However, my colleagues and I continued encouraging Anna to share her ideas and exchange feedback with her peers.

By presentation day, Anna was eagerly interacting with her peers, kept her camera on throughout the entirety of the class, and prepared a well thought out presentation to share with the audience. Anna's parents followed up with us in an email to let us know how Anna benefitted from participating in the MakerGirl program, including an increase in her self confidence and a renewed interest in STEM activities. In just five days, Anna gained many embodying traits of a Maker. She even returned for more 3D printing workshops with MakerGirl in the months following the five-day program. While not every student that participates in Making will experience as drastic of an impact as Anna did, I was able to see for myself how influential Maker education can be, and if it helps even one student, that's meaningful enough to me.

Characteristics of a Maker

A Maker can come from any background and they do not need any prior knowledge, experience, or access to the tools associated with Making in order to participate and be successful (Bevan, 2011). Although many STEM professionals have come to embrace the Maker Movement, Bevan (2011) points out that the movement was actually started by a "grassroots collective of hackers, tinkerers, crafters, and designers" (p. 77) looking for a community to share their creations as well as to provide resources and support in the creation of these artifacts. Halverson and Sheridan (2014) emphasize that most commonly, everyday people can be considered Makers due to the "democratizing nature of Making" (p. 497).

Through a four-year longitudinal study of youth Makers, Barton and Tan (2018) found that these Makers channeled their life experiences and their community ties into their work and their interactions with peers. Personal identities and backgrounds play a significant role in Making (Barton & Tan, 2018). Barton and Tan (2018) also found that it was highly valuable for students to engage with other members of their Making community, as this promoted a practice known as "co-making" (p. 779) and taught students how to navigate power dynamics with their peers while also supporting equity-oriented goals. Co-making is a way to make tools and knowledge more accessible, while also giving all participants a sense of agency, power, and recognition regardless of background.

Additionally, students were influenced by their personal experiences when it came to the actual artifacts they were creating (Barton & Tan, 2018). For example, youth were concerned about designing artifacts that were considerate of the user's economic status and safety from violence (Barton & Tan, 2018). One student concerned about the potential violence faced by teenage girls created a solar-powered rape alarm jacket that could be used to signal distress by the wearer when they were in danger (Barton & Tan, 2018). Another student concerned with disparities in accessibility to DIY videos created an open-access YouTube station to allow all members of the community to view videos (Barton & Tan, 2018).

Lastly, Barton and Tan (2018) found that students were able to recognize that race and gender could play a role in how one's legitimacy in Making could be perceived by others and how detrimental stereotyping can be to one's confidence. There are biases that persist in the portrayal of Makers.

Biases in the Portrayal of Makers

Vossoughi et al. (2016) points out that the ideal principles of Making are not the reality. Rather, Vossoughi et al. (2016) argues that the Maker Movement makes the underlying assumption that the experiences of the "European-American middle- and upper-class" (p. 211) are universal to all people. The "sameness as fairness" approach that many educational programs take "tend to design Making activities and environments with seemingly neutral or universal learning goals" (p. 214) but fail to consider that they have an implicit basis in the preferences and experiences of dominant populations (Vossoughi et al., 2016). This frames anybody outside of these dominant populations as the exception, with little consideration to their unique backgrounds cultivated by their cultures and families (Vossoughi et al., 2016).

Barton and Tan (2018) point out the prominence of damage-centered research that exists in the educational field, which views marginalized communities as inherently disadvantaged and in need of saviors from the more privileged groups in the majority. Instead, they favor a "desire-based framework" that looks at marginalized communities through a lens of possibilities and empowerment (Barton & Tan, 2018, p. 770). Low-income female youth need to be viewed through this desire-based framework.

Makerspaces

Functionally, a Makerspace is somewhere that a community of Makers can congregate to participate in Making activities (Halverson & Sheridan, 2014). Typically, Makerspaces have baseline equipment such as 3D printers, laser cutters, and woodworking equipment. However, Halverson and Sheridan (2014) emphasize that the Makers are what truly characterize a Makerspace. While well-funded schools are able to offer Makerspaces with tools and technologies to help students grasp STEM concepts and meet educational standards, "informal learning environments such as public libraries, museums, and independent nonprofits have expanded the notion of what gets made in makerspaces" (Halverson & Sheridan, 2014, p. 499) and allows Makers to explore their interests without penalty to their grades. Rather, Makers can view Making as an enjoyable collaborative activity rather than only viewing it as an independent learning experience. Libraries have historically offered free resources to their communities, making them an ideal place of accessibility for all Makers, and perpetuating the democratization of knowledge that is so fundamental to the ethos of Making (Halverson & Sheridan, 2014).

Distinguishing Maker Education from Other Types of STEM Programs

While Maker education typically falls into STEM education, not all STEM programs can be classified as Maker education. While some STEM programs may focus on conceptual learning, Maker education programs must emphasize experiential learning. Due to the different learning approaches, the consequent assessments to test students must differ as well. Maker education focuses on the application of STEM concepts rather than just their retention in the memories of students. According to Bevan (2011), Making has found its way into STEM education because educators are able to teach students concepts and then “develop or formatively assess students’ conceptual understanding by engaging them in the application of those understandings through design and engineering” (p. 76) in the context of Making. Marshall and Harron (2018) developed the Elements of Making, a framework for incorporating Making principles into STEM education; the following elements should be taken into account: “Ownership/Empowerment”, “Maker Habits”, “Production of an Artifact”, “Collaboration”, and “STEM Tools” (p. 4). The element of Ownership/Empowerment possesses the qualities of being personally meaningful and enjoyable to the Maker, whilst also remaining individualized and original (Marshall & Harron, 2018). The element of Maker Habits emphasizes a failure-positive approach that fosters growth and self-reliance within an individual (Marshall & Harron, 2018). A failure-positive approach acknowledges challenges and failures in the creation process but encourages persistence in improving the artifact and often requires more than one iteration attempt from the Maker (Marshall & Harron, 2018). The element of Production of an Artifact simply refers to the physical product or products of Making (Marshall & Harron, 2018). The element of Collaboration boasts connections within the community of Makers, as well as the sharing of tools and artifacts amongst Makers (Marshall & Harron, 2018). The element of STEM Tools refers to the digital and manufacturing tools required to create artifacts (Marshall & Harron, 2018). The framework developed by Marshall and Harron (2018) is consistent with the definitions provided by Halverson and Sheridan (2014) as well as Bevan (2011). Following this framework, Making can be appropriated into a learning environment.

The Maker Movement and the Gender Gap in STEM

Although there are no studies to suggest any significant differences between genders regarding math and analytic skills, there is a higher drop-out rate of women for STEM educational tracks and occupations compared to the drop-out rate of men (Raabe et al., 2019). This discrepancy creates and widens the gender gap in STEM (Raabe et al., 2019). While many students do not begin making serious decisions about their desired career path until they reach adolescence, exposing them to positive STEM learning environments at a younger age can influence their sense of self-efficacy and their preferences for learning certain subjects (Raabe et al., 2019). Raabe et al. (2019) found that an individual's favorite school subjects can help predetermine the educational and occupational careers that they choose to pursue. Thus, if girls are discouraged from pursuing STEM at an early age, there can be lifelong impacts on gender inequalities in socioeconomic status (Raabe et al., 2019).

The U.S. Department of Commerce cited gender stereotyping as a main contributing factor to the gender gap in STEM (Beede et al., 2011). Schön et al. (2020) found that educators often hold biases against female students after conducting a review of existing literature on girls and maker education, girls in makerspaces, and girls and robotics. For example, teachers may hold onto the belief that Makerspaces are not a safe space for girls to be working in or the belief that boys have a greater interest in technology and thus are more inclined to work with it (Schön et al., 2020). Whether or not this bias is conscious, it may affect the way teachers approach certain subjects, as well as the learning opportunities they may or may not provide to their students.

The U.S. Department of Commerce also cited a lack of female role models as another contributing factor to the STEM gender gap (Beede et al., 2011). Schön et al. (2020) found that girls tended to choose STEM workshops that were supervised by females, supporting the findings of Beede et al. (2011) and suggesting that girls find role models of the same gender to be more accessible and approachable. Additionally, the leading scholars in the field of Maker education research are women, including Vossoughi, Bevan, Halverson, Sheridan, Beuchley, and Barton.

The Maker Movement's Impact on Low-Income Student Motivation

Children that are from a lower socioeconomic status (SES) are at a higher risk of underperforming in STEM subjects (Banerjee, 2016). Banerjee (2016) identified several factors contributing to the underperformance of low-income students including familial factors, teachers' expectations, and school contextual factors.

A child's family plays a large role in their socialization and upbringing, as well as acting as a support system for them. Thus, familial factors such as "lack of parental academic involvement, authoritative parenting, [and] lower maternal education and family background" can make it challenging for students to find the motivation to perform well academically (Banerjee, 2016, pp. 5). One point of contention is how this parental academic involvement is measured. While it was not stated in the literature by Banerjee (2016), there is often an implicit basis in the experiences and perspective of the white middle class. Low SES parents may invest themselves in their children's academics in other ways that may not meet these formal standards. This is further confounded by the fact that Hispanic households and Black households earn the lowest incomes in the U.S. (Wilson, 2020). Because Hispanic people and Black people have different cultural norms and behavior around parenting, the standards set for how parental academic involvement looks can overlook these crucial differences (Lareau, 1987). According to Lareau (1987), a child's cultural experiences at home influence how that child adjusts to academic settings and approaches academic achievement, thereby acting as cultural capital. Thus, the view presented by Banerjee (2016) can be problematic in many cases due to a mismatch in cultural capital. However, if a child is truly not being supported by their family at home, they may instead seek this support from their teachers and peers, as they are likely to be surrounded by these people the most at school.

Teachers are especially influential in the academic performance of their students. Banerjee (2016) identified the strongest predictors of high academic achievement to be "students' relationship with teachers, perception of teacher sensitivity, and the reasons for attendance" (pp. 6). A teacher's influence on low-income students can sometimes be detrimental. For example, students from low-income backgrounds are more likely to be absent from school due to "their teacher's expectation of success and for the fear of humiliation in class" (Banerjee, 2 016, pp. 5). Additionally, there is a correlation between low-income students' higher perception of negative teacher feedback and those students' devalued perception of academics (Banerjee, 2016). Teachers have the opportunity to use their influence to foster positive results with their students too. Regardless of a student's risk status, Banerjee (2016) found that "positive teacher expectations, support, and motivation" can all have progressive effects on that student, though this holds particularly true for low-income students.

While students that come from more privileged backgrounds are able to place the majority of their focus on their studies at school, low-income students do not always have that luxury. Hsu et al. (2019) observed the influence of one afterschool Maker education program on middle school students' attitudes about science. They determined that students found greater value in science by being involved in the Maker education program because they were able to reaffirm and expand their career choices (Hsu et al., 2019).

Frameworks

Researchers in the field of education have sought out various methods of evaluating existing Maker education programs and creating more successful programs. Shah et al. (2018) devised an original framework called the Determinants of Success to be applied to STEM education programs in informal educational settings. Using the Theory of Planned Behavior (TPB) proposed by Ajzen (1991) in the field of social sciences, Jin et al. (2021) modified the existing TPB to be applied to Maker pedagogy in formal educational settings.

Determinants of Success (DoS)

Shah et al. (2018) propose a formal assessment tool called the Dimensions of Success (DoS) to examine quality indicators of STEM programs that take place during out-of-school time (OST) in informal educational settings. The DoS were divided into four domains (Shah et al., 2018). The domain of "Features of the Learning Environment" was related to the dimensions of organization, materials, and space utilization (Shah et al., 2018). The domain of "Activity Engagement" was related to the dimensions of participation, purposeful activities, and engagement with STEM (Shah et al., 2018). The domain of "STEM Knowledge and Practices" was related to the dimensions of STEM content learning, inquiry, and reflection (Shah et al., 2018). The domain of "Youth Development in STEM" was related to the dimensions of relationships, relevance, and youth voice (Shah et al., 2018). To utilize the DoS, each domain is scored numerically on a scale of 1-4 and the score is justified with evidence based on observations, field notes, and recordings (Shah et al., 2018). *Figure 1* summarizes the DoS.

Figure 1

The DoS Domains and Dimensions

Domain	Dimension	Rubric description
Features of the learning environment	Organization	Focuses on the extent to which the facilitator delivers the observed activities in a way that reflects appropriate planning and preparation, through having the necessary materials readily available, being ready to accommodate to changing situations, and having smooth transitions to prevent time loss and chaos in the learning environment.
	Materials	Focuses on the extent to which the activities make use of materials that are appropriate for the particular youth in a program, aligned with intended STEM learning goals, and appealing to youth.
	Space Utilization	Focuses on the extent to which the program space is utilized in a manner that is conducive to STEM learning in an OST environment.
Activity engagement	Participation	Focuses on the extent to which the youth have equal access to the activities offered. Participation refers only to general participation (access to materials, prompting to participate and contribute, etc.) in the activities and does not consider the degree to which the youth are participating in STEM thinking/reasoning or inquiry practices.
	Purposeful Activities	Focuses on the extent to which activities are structured so that youth clearly understand the goals of each activity, and the connections between them; it also examines the degree to which the facilitator uses his/her time productively to best support youth understanding of STEM learning goals.
	Engagement with STEM	Focuses on the extent to which youth are engaging in hands-on activities that allow them to actively construct their understanding of STEM content. It also looks at whether or not the activities leave youth as passive recipients of knowledge from the facilitator or as active learners who interact directly with STEM content so they do the cognitive work and meaning-making themselves.
STEM knowledge and practices	STEM Content Learning	Focuses on the extent to which youth are supported to build understanding of science, mathematics, technology, or engineering concepts through STEM activities. Observers must consider the accuracy of STEM content presented during activities, the connectedness of STEM content presented during activities, as well as evidence of youth uptake of accurate STEM content based on their questions, comments, and opportunities to demonstrate what they learned.
	Inquiry	Focuses on the extent to which activities support the use of STEM practices. These STEM practices are usually used in the service of helping youth learn the science content more deeply. Stronger quality involves youth participating in STEM practices in authentic ways (versus superficially going through the motions of inquiry) to pursue scientific questions, address a design problem, collect data, solve an engineering task, etc.
	Reflection	Focuses on the extent to which activities support explicit reflection on the STEM content in which the youth have been engaged. This dimension also refers to the degree to which the quality of youth reflections is superficial or meaningful and connection-building.
Youth development in STEM	Relationships	Focuses on the extent to which the facilitator has positive relationships with the youth and other facilitators as well as the extent to which youth have positive relationships with each other.
	Relevance	Focuses on the extent to which the facilitator makes connections between the STEM activity and the youth's lives and personal experiences, other subject areas, or a broader context.
	Youth Voice	Focuses on the extent to which the STEM activities encourage youth to have a voice by taking on roles that allow for genuine personal responsibility and having their ideas, concerns, and opinions acknowledged and acted upon by others.

Note. From "Improving STEM program quality in out-of-school-time: Tool development and validation" by A. M. Shah, C. Wylie, D. Gitomer, G. Noam, 2018, *Science Education*, *102*(2), p. 242(https://doi.org/10.1002/sce.21327). Copyright 2018 by Wiley Periodicals, Inc. Reprinted with permission.

Shah et al. (2018) determined that DoS was an appropriate tool that could be used in the education research because it was general enough to be utilized for a variety of programs catered to informal education settings while also being specific enough to STEM education that it could "lead to concrete feedback and conversation about programming needs and improvement" (p. 253). While Shah et al. (2018) did not create the DoS specifically to evaluate Maker education programs, the four domains of the DoS are relevant to Making and are thus appropriate to use as a metric.

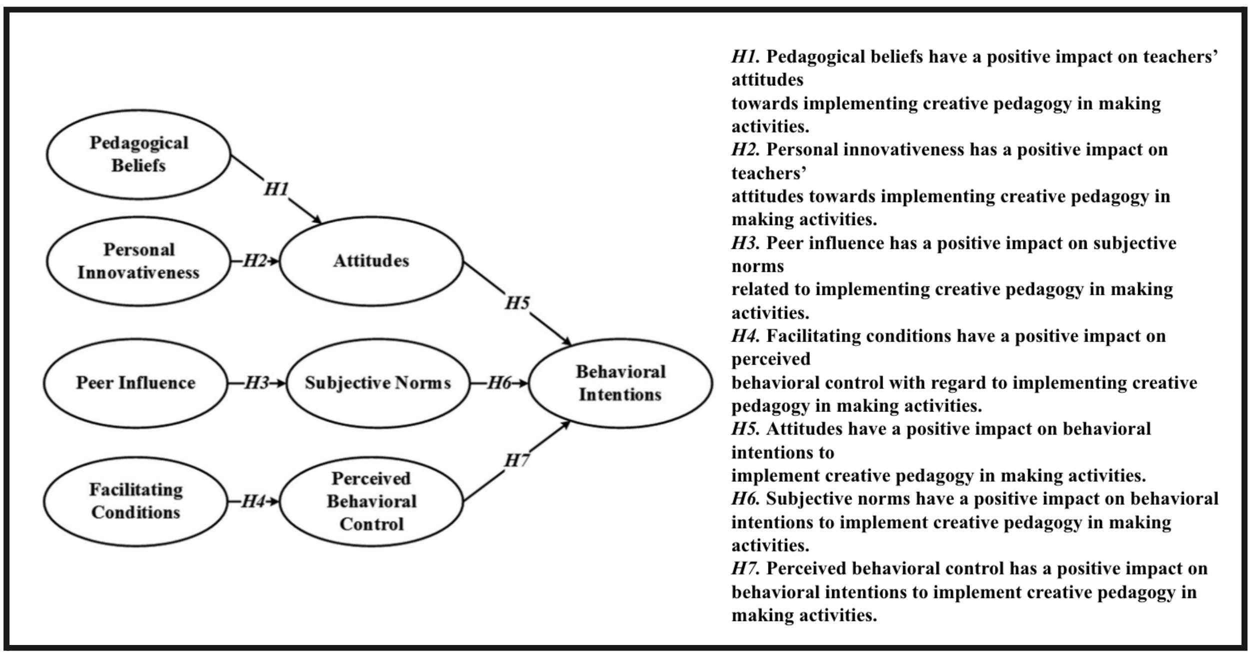
Theory of Planned Behavior (TPB)

Ajzen (1991) proposed the Theory of Planned Behavior (TPB) as a framework to explain and predict human social behavior by tracing "attitudes, subjective norms, and perceived behavioral control to an underlying foundation of beliefs about the behavior" (p. 206). In order to change an individual's behavior, any form of intervention must be aimed at changing their beliefs about their behavior. Different aspects of their behavior can be described in terms of "intention, perception of behavioral control, attitude toward the behavior, and subjective norm" (Ajzen, 1991, p. 206).

The TPB has been utilized in a variety of social sciences, but Jin et al. (2021) was able to apply it specifically to the evaluation of Maker educators and program facilitators. Jin et al. (2021) conducted a study with primary and secondary in-service teachers that taught subjects related to Making, such as "information technology, science, and art," and they included Making into their curriculum (p. 33). The purpose of the study was to determine how their attitudes towards pedagogy affect student outcomes when implementing Making into the formal classroom (Jin et al., 2021). This study has a basis in the TPB, which focuses on the effect of an individual's personal beliefs and self-efficacy when it comes to the decision-making process (Jin et al., 2021). The teachers participated in a professional development program that taught teachers concepts relevant to Making, such as 3D printing, programming, robotics, and creating drones (Jin et al., 2021). Jin et al. (2021) then developed a follow-up survey to be given to these teachers to record their perceptions toward implementing more Making activities into classroom instruction. The adapted TPB by Jin et al. (2021) is summarized in *Figure 2.*

Figure 2

TPB Model Proposed by Jin et al. (2021)



Note. Adapted from "Perceptions of teachers regarding the perceived implementation of creative pedagogy in "making" activities" by H. Jin, C. Su, C. Chen, 2021, *The Journal of Educational Research, 114*(1), p. 32(https://doi.org/10.1080/00220671.2021.1872471). Reprinted with permission.

Jin et al. (2021) found that the teachers' attitudes toward behavior were significantly influenced by their "pedagogical beliefs and personal innovativeness" (p. 34). For example, when kindergarten teachers had the chance to experience more creative activities in the classroom, they had more confidence in their ability to foster creativity from their students, which could positively impact "their willingness to implement the teaching of creativity" more regularly (Jin et al., 2021, p. 34). Additionally, the peer influence imposed on teachers by their colleagues could affect their willingness to implement Making into curriculum (Jin et al., 2021). By allowing creative activities and Making to become a norm in the school, more teachers had the chance for greater interaction with their colleagues, leading to increased implementation in the whole school (Jin et al., 2021).

Because the experience in formal educational settings is predominantly driven by the decision-making of teachers, the TPB is an appropriate framework that can be used to evaluate Maker pedagogy that has been incorporated into the existing curriculum.

Choosing a Framework

The framework that will be used to evaluate my proposed program is the DoS developed by Shah et al. (2018). This is because the adaptation of the TPB by Jin et al. (2021) can only be applied to formal educational settings, where educators are more likely to form a long-term work culture with their peers. While strong interpersonal relationships may still develop between educators for extracurricular informal educational programs, it may not be as likely that their behavior influences one another significantly in the workplace. Educators that involve themselves in informal education typically do so because they already have an interest or motivation to supplement formal classroom education with an alternative learning method. Often, people that volunteer for extracurricular Maker education programs do not need to be convinced of the importance or impact of Maker education and creative experiential learning for young students. Rather, they are already invested by motivations beyond the beliefs and behaviors of their colleagues.

The DoS framework by Shah et al. (2018) also allows for the evaluation of a Maker education program through multiple domains. This gives a more well-rounded perspective of the program's performance. Additionally, this allows for multiple avenues of improvement to target. While the DoS framework was originally created to evaluate informal STEM educational programs, I argue that using the DoS framework for formal educational settings that have implemented Making could still provide an equitable assessment of the program. Regardless of the modality of a program, the proposed domains of DoS are important factors to consider when trying to create curricula that effectively conveys the principles of Making while providing enriching STEM content. The dimensions of the DoS are areas that can be improved upon regardless of the educational setting.

Implementation of Making into K-5 Education

There are many considerations that come with determining whether Maker education should be implemented into formal education or informal education. Formal education is a term referring to the classroom setting, where students are expected to learn curriculum mandated by the school district and the state education board. Informal education is a term referring to extracurricular settings such as libraries and educational programs that take place after school or during the summer. While 'informal' may have a negative connotation colloquially, in the field of education, it is meant only to denote the setting and structure in which learning takes place and in no way implies the value or validity of the program.

Considering the Challenges of Establishing a Maker Education Program

In order to create a Maker education program that successfully fulfills the standards set up by the DoS framework proposed by Shah et al. (2018), there are several logistical barriers that must be overcome. These must be considered when choosing between implementing Maker education programs in formal or informal educational settings.

The Cost of Maker Education Programs

Establishing a Maker education program is often associated with a high upfront cost, especially if the program organizers do not already have access to a Makerspace. Davis (2016) estimates that schools spend an average of $50,000 on Makerspace equipment. Additionally, there are often annual operating costs associated with equipment maintenance and keeping the Makerspace well stocked with supplies. Funding for Makerspaces can come from donors, grants, fundraising, and personal contributions. However, Maker education programs are most accessible when participation comes at no cost to the students. Alternatively, Makerspaces may already be open for use by the community in public locations such as libraries. Renting a Makerspace may require more planning on the program organizers' end, and there may be a fee associated. While facilitators of Maker education programs can be volunteers, compensation for these educators is yet another cost that should be considered for not only the time they spend teaching students but also the time it takes for them to undergo training.

Training for Maker Educators

Educators must undergo training in order to properly facilitate curriculum and consistently maintain the integrity of Making pedagogy when teaching for a Maker education program. Maker educators are required to be knowledgeable about the STEM curriculum being taught, the modality of experiential learning, and the use of software and equipment. If an in-service teacher takes on the additional role of a Maker educator, that teacher is not guaranteed to be fully financially compensated for their training or any time spent modifying existing curriculum for formal education or facilitating informal extracurricular programs. In-service teachers are required to undergo professional development every year to maintain their licensure status, but the amount of time that it takes to adequately prepare new teaching materials and fully integrate Maker pedagogy may go beyond the few paid professional development days provided by the school. While less than 20% of Makerspaces have a full-time director, delegating a teacher or program organizer to take on the role of managing the Makerspace should be considered (Davis, 2016).

Student Transportation

Program scheduling may serve as a barrier to some students. Especially in the case of informal educational programs, even the most motivated students may not be able to attend if they do not have a safe and reliable form of transportation to and from the Makerspace. Schools are able to provide free bus services.

Virtual Programming

One possible solution to address student transportation is offering completely virtual programs. In response to the COVID-19 pandemic, existing STEM and Maker education programs such as MakerGirl and GE Girls began offering virtual classes, which broadened accessibility from only students in local communities to students in various states and even different countries that would not have the chance to enroll in these programs otherwise.

However, this modality of learning comes with its own set of challenges. Virtual programs place the majority of the burden on students and their parents to provide functional technology, a reliable internet connection, and a quiet place to work. Younger students may still have to rely on their parents in order to troubleshoot any technological issues that may arise, and program instructors have little to no control over the student's learning environment.

Parental Support

Parents and guardians often contribute to a student's academic success and extracurricular involvement based on how supportive they are. While some parents are able to invest a considerable amount of time and money into their children's education and other interests, it is a privilege that not all families have. Some parents may have to work long hours or care for multiple children. Some parents may not be able to afford the associated costs with participating in a Maker education program. Some parents may be unfamiliar with the benefits of Maker education and other types of STEM enrichment programs. Parents are not burdened as much with these barriers when all students are equally offered Maker education during the school day.

Making and Formal Education

Because all students are already required to attend school, implementing Making into the existing required curriculum could be the solution to student accessibility.

Benefits of Implementing Making into Formal Education

By incorporating Making into formal curricula, schools can maximize the amount of students that are able to experience Making (Nemorin, 2016). Learning STEM concepts through the context of Making can help students make direct connections to the required curriculum. The unique experience-based learning can help with information retention and prepare students to tangibly apply these STEM concepts in contrast to traditional learning that may lead to "teaching to the test" and information regurgitation.

Limitations of Implementing Making into Formal Education

The principles of Making are often limited by the standard requirements of the school district and the state education board (Nemorin, 2016). The responsibility of implementing Making into standard curriculum also falls heavily onto teachers and other educators. They will be required to attend extra training and professional development programs similar to those used in the study by Jin et al. (2021). However, school administrators may not be required to or may lack the funding to financially compensate them for undertaking this training, because they are under no obligation to focus on Maker education.

Even if teachers are successfully able to deliver STEM curriculum to students while incorporating Making pedagogy and activities into the lesson plan, there is the additional challenge of evaluating students. The teacher's ultimate goal must be to ensure that students are able to retain and apply the concepts they were taught. Making is an active process; thus, it is ideal for students to be assessed through practicum testing instead of traditional standardized testing for a more authentic evaluation. Because of the degree of subjectivity that comes with grading practicums, practicum testing is typically not used on a district-wide or state-wide basis for core subjects. It is difficult to standardize data and draw conclusions about the performance of teachers and schools when practicum test scores are used. If teachers were to use practicums to evaluate their students' knowledge of the course material then in practice, they would likely have to administer the practicum testing in addition to all the traditional multiple-choice and written exams required by the school district and the state education board. Teachers will likely be strained for time to thoroughly cover concepts in class if they must prepare students to meet the standards outlined by these entities while also attempting to evaluate them fairly through practicums. It is a difficult tradeoff that requires a sacrifice of the students' learning experience.

If Making is already included in a student's regular school day, any underlying biases in their learning environment and their educator's teaching style could be perpetuated. Schön et al. (2020) found that focusing on the girls in the class is important for them to gain confidence in STEM, as they will not feel as valuable in the STEM field if their teacher does not engage as much with them as they do with boys. In this case, having consistency in the existing classroom culture could be detrimental to the efforts being made towards empowering the female students if the classroom discussions and interactions are dominated by their male peers.

While teachers should ideally care about the long term success and wellbeing of their students, they ultimately are not accountable for what their students do after they graduate from secondary school. With the demands of the school district and state education board to meet benchmarks and raise scores on standardized examinations, teachers are not always able to focus on cultivating their students' personal interests and plans after graduating even if they have the desire to. On the other hand, these educators are obligated to meet standards created by administrators so that students are able to graduate. Thus, teachers must prioritize their obligations when planning their curriculum.

Making and Informal Education

By creating a Maker education program that is unique and separate from the existing required school curriculum, students have a low-stakes manner of learning STEM concepts without being limited by standards set by the school district and the state education board. Making in informal educational settings could be the solution to addressing the gender gap in STEM.

Benefits of Implementing Making into Informal Education

The integrity of Maker pedagogy can best be maintained in informal education outside of school settings because students are better able to explore their own interests when their grades in school are not affected (Hsu et al., 2020). While it may be argued that students can feel more incentivized by the opportunity to raise their grades with assignments related to Making, the loosely structured, self-driven nature of producing artifacts makes it challenging to put on an equitable grading scale when every student follows their own independent inquiry. Hsu et al. (2019) found that informal learning environments took pressure off of students to learn required curriculum and increased their confidence, whereas learning science in formal educational settings had previously felt discouraging to them.

While traditional teaching methods typically prioritize the creation of objective and neutral designs over personalization, Kafai et al. (2014) found that creative expression is an integral part of mastering technology. Therefore, focusing on aesthetics and making designs personal to the Maker cannot be separated from learning (Kafai et al., 2014). Personalization of projects is one way that students can demonstrate ownership of their learning (Marshall & Harron, 2018). Rather than promoting the idea that making a project look aesthetically pleasing is a waste of time, informal educational settings have more freedom to spend time on developing students' creative process. Students are more likely to enjoy Making and learning about STEM topics if they are not penalized for being creative and having fun. This sense of ownership and enjoyment can contribute to increasing a student's sense of self-efficacy and sense of belonging in STEM.

In informal educational settings, students may also get a chance to work with new educators and a new group of peers, allowing them to learn in a new environment outside of the traditional classroom. Usually, the groups may be smaller and the program facilitators may be better attuned to offering their attention to the students that need it. Being in an afterschool Maker education program improves students' opinions about STEM and confidence in themselves (Hsu et al., 2020).

Limitations of Implementing Making into Informal Education

Being able to attend extracurricular programs such as an informal STEM enrichment program is a privilege that not all students may have. While informal education allows greater freedom in selecting a Makerspace or location to host meetings, students will have to consider finding a safe, reliable, and consistent mode of transportation in order to attend. Even with virtual programs, there is the flawed expectation that a student will have the necessary technology, a stable internet connection, and surroundings that are conducive to learning. Again, low-income students and their parents will especially be burdened by these requirements for participation.

Summarization of Findings

The findings of the literature can be summarized in *Figure 3* and *Figure 4*. *Figure 3* compares the benefits and limitations of Making in formal education. *Figure 4* compares the benefits and limitations of Making in formal education. While Making in formal education offers considerable benefits, it is outnumbered by the limitations identified in this thesis. Making in informal education offers an overall larger quantity of benefits and an overall lower quantity of limitations identified in this thesis. I argue that for Making in informal education, the benefits outweigh the limitations enough to be viable for the creation of an informal Maker education program.

Figure 3

Maker Pedagogy in Formal Education

Benefits	Limitations
● All students will have access to Making ● Schools may have access to a Makerspace and/or relevant technologies for Making ● Parents are not burdened as much with barriers to participation	● Artifacts and projects produced through Making are difficult to grade in a manner that is compatible with standards set by the state and school district ● Teachers bear the greatest responsibility of program implementation ● Current classroom culture and dynamics between students are perpetuated ● Funding must be allocated from the provided school budget

Figure 4

Maker Pedagogy in Informal Education

Benefits	Limitations
● Programming can be made to better suit specific demographic groups ● Curriculum does not have to conform to any standards set by the state or school district ● Students have a chance to learn in a low-stakes environment that allows them to focus on learning rather than grades ● Students enrolled in the program can be capped so that there are smaller groups of students working together ● Students can be evaluated through practicum testing rather than traditional standardized testing ● Grades are not required, so students are able to focus on personalization of their projects and having fun	● Parents bear the greatest responsibility of ensuring student participation ● Funding must be acquired

Proposal

I propose designing a Maker education program that can be implemented into an informal educational setting, provided that the program is made not only accessible to, but specifically palatable to, female low-income students.

Recommendations for Addressing the Gender Gap in STEM with Making

If the goal of a Maker education program is to bridge the gender gap in STEM and provide more learning opportunities to young female students, it is imperative to create a program that is palatable to them. Schön et al. (2020) found that using gender-sensitive language in educational materials can make STEM topics feel more approachable. They also found that girls are more motivated to participate if the value of an activity is emphasized in its title; in other words "if a title of the event or activity includes not only its contents, e.g. 'Robotics with kids'", but also allows students "to get a sense of value of the activity, e.g. 'Robotics for gardeners'" (Schön et al., 2020, p. 194).

The team of Maker education program facilitators should also feature female educators, as the findings of Schön et al. suggest that girls find role models of the same gender to be more accessible and approachable (2020). Schön et al. (2020) recommended that programs should aim for a gender ratio of at least 1:1 for girls and boys, ensuring that female students are either in the majority or in an equal proportion to male students.

The collectivist nature of Making can make STEM less intimidating for girls, as they typically prefer collaborative activities (Schön et al., 2020). This can be attributed to the inherent implication that there is an expected positive outcome for all of the contributors to the activity without the pressure of competition (Schön et al., 2020). This type of Makerspace culture could foster the co-making practices described by Barton and Tan (2018).

Recommendations for Promoting Academic Success for Low-Income Students

Introducing students to potential STEM careers and role models that they can relate to early in their academic experience is an effective way to encourage them to set goals for themselves. Maker education programs could take the time to teach students about prominent figures in various STEM fields that came from low-income backgrounds. Using value-based titles for programs per the recommendation of Schön et al. (2020) could also be helpful in introducing a variety of STEM careers and fields of study to low-income students.

Funding

In order to eliminate the potential barrier that participation fees may cause, I propose to allow all students to attend free of charge. Instead of parents paying for classes, funding would come in the form of grants, donations, and partnerships with local community organizations and corporations.

Limitations

While pursuing higher education and entering the STEM field can serve as a means for vertical socioeconomic mobility, there are a multitude of other factors that contribute to the cycle of generational poverty. Additionally, pursuing a degree at a four-year institution is not the only pathway that can lead to a high-paying career. For example, trade programs and apprenticeships that prepare their students to perform highly-skilled labor are other viable paths. In discussing careers and higher education with youth, Maker education programs and educators should not be biased in their presentation or show favor towards one path over another. Rather, students should be supported and viewed with dignity through the desire-based framework described by Barton and Tan (2018).

Minority groups should not be treated as a monolith. While the existing literature makes generalizations about Makers based on data collected, educators should be conscious of the needs of individual students enrolled in their program. Barton and Tan (2018) emphasize the role of a Maker's personal experience in producing their artifacts.

Discussion

Following the recommendations made by the existing literature on Maker education and STEM education, my proposal fulfills the DoS framework developed by Shah et al. (2018). My proposal is justified using the DoS framework, which is summarized in *Figure 5*. Informal educational programs do not have to abide by standards of the school district or the state, so there is freedom to emphasize creativity, self reflection, mistakes, and iteration. Students are not pressured by graded assignments and can instead see STEM as a fun and approachable field that they belong in. Giving low-income female youth a positive experience in STEM at a young age can increase their confidence and make them more likely to pursue STEM careers in their adulthood. Additionally, the failure-positive Maker mindset contributes to resilience (Marshall & Harron, 2018).

To satisfy the domain of *Features of the Learning Environment*, my proposal targets the dimension of *Organization* by providing program facilitators with greater leeway than in-service teachers to make case-by-case decisions to accommodate student needs. My proposal also satisfies the dimension of *Materials* by allowing for the use of unconventional Making technologies that typically aren't emphasized in formal STEM classrooms such as sewing. Additionally, the *Space Utilization* dimension is satisfied as long as informal programs provide students with an environment that is conducive to STEM learning and Making. They also have more flexibility in choosing a location than schools. While funding will need to be acquired in order to satisfy this domain of *Features of the Learning Environment*, it is attainable, as discussed in the previous section.

Because there are no school board requirements to abide by, my proposal is able to satisfy the domain of *Activity Engagement*. By designing a program that is targeted to young female students, educators are better able to prompt them to contribute and participate, which satisfies the dimension of *Participation*. Program activities can be structured so that students have a clear understanding of the goals of each activity, as well as the connections between them, which is the main focus of the dimension of *Purposeful Activities*. The *Engagement in STEM* dimension is satisfied when program activities take on a more active and hands-on learning approach.

The *STEM Knowledge and Practices* domain was the most challenging to satisfy with my proposal, as this is the main focus of formal education and my proposal aims for the absence of graded assignments. Educators are responsible for delivering accurate STEM content to students, which satisfies the dimension of *STEM Content Learning*. Students are able to pursue scientific questions, address a design problem, collect data, solve an engineering task, and much more, which contributes to the dimension of *Inquiry,* all without the pressure of being graded. Additionally, informal education allows for the development of activities that support the students' explicit reflection on STEM content, satisfying the dimension of *Reflection*.

The final domain of *Youth Development in STEM* can also be addressed with my proposal. An informal educational setting allows students to create meaningful relationships amongst themselves and with an educator that is committed to empowering them in STEM, satisfying the dimension of *Relationships*. To address the dimension of *Relevance*, there is a greater opportunity to make connections between the STEM curricula and the youth's lives and personal experiences, other subject areas, or a broader context because there are no standard requirements to be met. Finally, to satisfy the dimension of *Youth Voice*, in informal education youth can be encouraged to have a voice by taking on roles that allow for genuine personal responsibility in projects and STEM inquiry without the added pressure of grades or competition. The domain of *Youth Development in STEM* is a particularly important component in building a student's self-efficacy and resilience because it emphasizes and empowers their role as a Maker.

Figure 5

Proposal in the Context of DoS

Domain	Dimension	Proposal
Features Of The Learning Environment	Organization	Program facilitators have greater leeway than teachers to make case-by-case decisions to accommodate student needs
	Materials	Informal education allows for the use of unconventional Making technologies that typically aren't emphasized in formal STEM classrooms (e.g., sewing)
	Space Utilization	Informal programs must provide students with an environment that is conducive to STEM learning and Making, but because they are not required to be affiliated with a school, they have more flexibility in choosing a location.
Activity Engagement	Participation	By designing a program that is made for young female students, educators are better able to prompt them to contribute and participate.
	Purposeful Activities	Because there are no school board requirements to abide by, program activities can be structured so that students have a clear understanding of the goals of each activity, as well as the connections between them.

	Engagement with STEM	Because there are no school board requirements to abide by, program activities can take on a more active and hands-on learning approach.
STEM Knowledge and Practices	STEM Content Learning	Educators are responsible for delivering accurate STEM content to students.
	Inquiry	Without the pressure of graded assignments, students are able to pursue scientific questions, address a design problem, collect data, solve an engineering task, etc.
	Reflection	Without the pressure of graded assignments, informal education allows for the development of activities that support the students' explicit reflection on STEM content.
Youth Development in STEM	Relationships	An informal educational setting allows students to create meaningful relationships amongst themselves and with an educator that is committed to empowering them in STEM.
	Relevance	Because there are no school board requirements to abide by, the educator has a greater opportunity to make connections between the STEM curricula and the youth's lives and personal experiences, other subject areas, or a broader context.
	Youth Voice	Without the pressure of graded assignments, youth can be encouraged to have a voice by taking on roles that allow for genuine personal responsibility in projects and STEM inquiry.

Conclusion

Making is an effective avenue for delivering STEM education to low-income female youth in a manner that is unique from traditional pedagogy. In this thesis, I looked at Making in the contexts of formal education and informal education and made comparisons between the two learning environments before proposing a Maker education program of my own.

In formal educational settings, there are still barriers to implementing Making into the classroom that are challenging to overcome due to the systemic nature of the educational system. Making has not been identified as a primary goal of formal education, where the emphasis is on learning content rather than learning how to become competent in doing things. Unfortunately, the goals of formal instruction do not always align with the principles of Making, even contradicting these principles at times. The more that you try to ensure that Making curricula covers the goals and priorities of formal education, the less Making will exist at its optimal level.

To reiterate the formal definition of Making, there is an emphasis on "materials-based investigations" (p. 75), as well as experiential learning and self-driven inquiries, which demonstrates a clear departure from a focus on purely conceptual learning (Bevan 2011). Informal educational settings are the best place to cultivate these experiences because rather than viewing Making as another subject to master in school, students are able to experience and appreciate Making for what it is. When the creative processes are stripped from Making to meet specific standards, it arguably is not even Making anymore.

Informal education also allows the program to be targeted to the demographics that may lack access to Maker education otherwise. By following my proposal, low-income female students can find themselves in a learning environment that accommodates their specific needs and uplifts their identities as an integral part of their creations. Participating in Maker education is not the sole determinant for any youth's future career. However, the goal of Maker education programs, such as the one I am proposing, is to help students cultivate a positive relationship with STEM starting from a young age. This is where self-efficacy and resilience come into play.

Students will have the chance to develop their mindset of future goals as well as their mindset for overcoming any adversity that they may face by being female, being from a low-income background, and being at the intersection of both. When the time comes for them to decide which career to pursue, it will hopefully be a matter of whether they *want* to be a part of the STEM field rather than whether they *feel capable* of being a part of it.

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Author Biography

Elvi was born in the City of Urdaneta in the Philippines and immigrated to Tomball, Texas right after her third birthday. From a young age, she was always passionate about two things: science and helping people. She graduated in the top 1% of Klein High School's class of 2018 and began her undergraduate studies at the University of Texas at Austin in the following semester. While she entered UT as a Public Health major and planned to pursue medical school, she realized that the lifestyle of a clinician was not something that felt like the right fit for her. Rather, she wanted to focus on broader social and environmental issues through the lens of public health. During her sophomore year, she began volunteering with MakerGirl. More about her experience at MakerGirl is discussed in the Positionality Statement. During her junior year, she began pursuing Linguistics as a double major for the sake of her own academic enrichment and fell in love with another field. While she does not intend on pursuing a career in linguistics, she is grateful for the opportunity to learn about the subject.

All of the jobs Elvi has ever held were related to teaching, from tutoring youth, to teaching martial arts, to mentoring peers and becoming a teaching assistant at a UT research lab, to volunteering with MakerGirl. After graduating, she plans to take a gap year before pursuing a Masters in Public Health. During her gap year, she intends to continue working with MakerGirl as a paid member of their staff. While a lot of the future is still unclear for Elvi, she hopes her eventual career stays true to her passions of science and helping others.