MAKING SPACE

Pedagogical Interventions to Foster Equity in Introductory Maker Education

By

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ABSTRACT

The maker movement has spread widely among both adults and children, but its recent integration into K-12 education has forced makerspace coordinators to examine their work through a new lens. Experienced makers need little beyond safety training to get started making their own projects, but new makers, particularly young students, need more. Without properly scaffolded introductory activities, inexperienced students quickly become discouraged and opt-out of maker activities. This thesis explores possible pedagogical guidelines for introductory activities that create more inclusive educational makerspaces.

Education theorists and maker educators consistently express a need to support beginners, but the exact type of support differs. Some foster equity by choosing non-gendered introductory projects that can be easily modified for personal customization. Many suggest that the most useful support comes from creating a maker community, typically by leveraging both peer interactions and mentor relationships. In the workshop I taught, I tested my lesson plan both with and without explicit emphasis on peer feedback. The sections with an emphasis on peer feedback were more creative, social, and willing to ask questions than the sections without it.

Though their techniques for creating community may differ, educators must be aware of the psychological barriers that keep students from making. Some students claim that they lack certain skills, whether technical or creative, that are necessary to make an original project. Others believe that makerspaces are only for "smart people" or "engineers" and do not view themselves as part of those groups. And still others are eager to get started, but simply lack the economic privilege necessary to continue work with expensive tools at home. All of these students need different types of support, but they will all benefit from a community where they view their mentors and peers as sources of inspiration and feedback instead of as unsurpassable competition.

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Introduction

Learning a new skill or experiencing a new subject area for the first time can be an intimidating experience for many students. Nearly every child struggles through their first attempts at reading or doing basic arithmetic, perhaps even declaring "I give up!" until being forced to continue by a well-meaning teacher or parent. Artists often hide or throw away their earliest work. Star athletes might have lost their temper after missing a series of shots in an early practice. Skaters fall, mathematicians fail to wrap their brains around fundamental concepts, and interpreters forget basic words in their second language. And yet, something about these disciplines makes students press on, get back up, and keep learning. In some cases, it might be the fact that the topic is considered so fundamental to societal success that teachers simply refuse to let the student progress without that knowledge. In other cases, internal motivation or a sense of identity pushes students to overcome minor failures in pursuit of a larger goal. Teachers in most disciplines have developed an understanding of common failures, common motivations, and ways to push students forward in their discipline. It is hard to imagine that many students would learn addition if they were just put in a room with blocks and a number line and told to "figure it out", and yet that is exactly what many makerspaces do with beginning makers.

The phrase "Maker Movement" refers to a recent explosion in the number of spaces designated for members and visitors to design and build physical projects. These spaces take on many names: machine shops, fabrication labs, makerspaces, and hackerspaces are just a few. For the purpose of this thesis, I will use the term "makerspace" to refer to any and all of these. A typical introduction to a makerspace includes some sort of basic safety training and varying amounts of technical training, whether through demos or hands-on workshops. For a generation who spent time in home economics courses, shop class, or working on cars and bikes in their garages, a basic safety training might suffice to get started, but the average student these days needs much more. In this thesis, I will focus on students who are new to making things or who have experience in a field like cooking or painting that could be considered a form of making but is not typically done in a makerspace context.

For more experienced makers, a focus on the newest and most complex technology may be valuable, but newer makers can lose motivation when faced with learning safety, complex machines, specialized software, and design principles simultaneously. Many makerspace directors attempt to solve this dilemma by focusing on 3D printers. But while novel and impressive for the first few prints, most low-end 3D printers quickly reveal their limits, whether in detail, size, or structural integrity, and become at best a tool for rapid prototyping and making key chains and trinkets to give as holiday gifts. At the same time, traditional machine shop equipment, ranging from classic woodworking machines like band saws and drill presses to newer and more high-tech machines like laser cutters and CNC mills, comes with cost and safety barriers that prevent its introduction into most public schools.

Make:, a widely consulted source for maker news and project ideas, does an annual ranking of 3D printers. Their 2017 list included some specially recommended for schools, but even these relatively affordable printers ranged from $400 to $1900 and the only one below $900 came with a maximum build volume of just 4"x4"x5" ("3D Printer Buyer's Guide," 2017). To get a low-end laser cutter from a reputable company, the cost is significantly higher, on the order of $5,000 ("COMPARISONS | Voccell - The Laser People," n.d.). By comparison, a Silhouette Cameo, a vinyl cutter Make: calls "fast, accurate, and versatile", is available as a starter kit bundle for only $230 on Amazon, with its smaller "portrait" version available for only $145 (Griffin, 2015).

Barring a sudden influx of cash and qualified safety training professionals into the public-school system, laser cutters and 3D printers may remain out of reach for many, but the more affordable vinyl cutter could provide the key to effective maker education in K-12 schools. Despite its name, the vinyl cutter is by no means limited to vinyl, and can in fact cut paper, foil, thin plastic sheets, fabric, and nearly any other flat material that one might considering cutting with a craft knife or scissors. Like makerspaces themselves, vinyl cutters also go by a variety of names: craft cutters, CNC die cutters, etc., but for simplicity I will use the term "vinyl cutter" to refer any of these computer-controlled paper cutting machines. Though vinyl cutters are not as powerful or versatile as laser cutters, I believe they provide three main advantages that public schools would be foolish to ignore:

1. **They are accessible for instructors.**
   For just a couple hundred dollars plus the cost of materials to cut, a vinyl cutter can be up and running in any classroom. It requires no more space than a typical student desk, does not need ventilation or any other safety equipment, and can be run without any training or technical background. It simply requires a wall outlet, a USB connection to a laptop, and a simple software download to get started. Beyond that, it is simple to maintain, mainly just requiring the replacement of the $10 cutting blade when it gets dull or breaks, whereas 3D printers and laser cutters often require a trained professional to maintain them, no small feat in a rural or low-income context.

2. **They can be used by students of any age.**
Vinyl cutters work by exposing only a very small part of a cutting blade, making them even safer than a typical craft knife or pair of scissors, so they are safe for elementary school students to use with minimal supervision. However, they are capable of cutting complex designs produced in a wide variety of software, so older students can still push the boundaries of software and materials.

3. **They are simple and reliable enough to be a tool rather than a primary focus.**
A student would never consider learning Microsoft Word to be the main focus of writing an essay, but using a tool like a 3D printer comes with so many complications and constraints that the use of the tool is more of the focus than the product itself. Vinyl cutters can be used to produce stickers or intricate paper art where the product of the actual cutting is clearly visible, but they can also produce things like precisely shaped adhesive sheets, intricate copper circuits, or stencils for screen printing, allowing the design and final product to be much more of a focus than the machine itself.

With these factors in mind, I designed and tested an introductory activity that uses a vinyl cutter as a canvas for teaching basic principles of design and making that will be applicable across machines. My main goal was adaptability, creating a system that can be implemented by teachers in a variety of contexts with different types of students. For this reason, I chose the Silhouette Cameo for my research, as it is affordable enough to be obtained by most schools but powerful enough and big enough (one foot in width and capable of cutting long rolls) to work for a variety of projects.

The Silhouette also comes with the benefit of having a fairly powerful and user-friendly software that is freely available. While very complex or precise designs will still require the use of more advanced CAD or vector illustration software, the Silhouette Studio software allows students an easy platform to trace existing images and manipulate lines and shapes in useful ways before sending their designs to the cutter. The software's ability to take in and trace image files also offers students what Scratch creator Mitch Resnick refers to as "wide walls", the ability to take a product or process in a variety of directions instead of following a prescribed path from the "low floor" (easy entry level) to the "high ceiling" (advanced use case) (2016). An electronics-inclined student can model a circuit board in Eagle and then cut the traces on a vinyl cutter while a more artistically-minded student can scan a drawing or painting they made and cut a sticker based on that. The platform does not dictate the final product.

Because of this flexibility and a relative lack of documentation surrounding creative uses of vinyl cutters, the main goal of my research will be to expand these wide walls and reveal to teachers how to continue widening them in their own classes. While some students navigate these wide walls on their own, a truly equitable makerspace provides guidance that can help students of all genders, races, and socio-economic backgrounds feel comfortable and confident with making. To achieve this goal, I intend to focus on the educational concept of scaffolding, a popular technique in traditional learning environments but one that is often neglected in makerspaces. I aim to answer the question "How does introductory maker instruction impact who becomes a lifelong maker?" by identifying and testing the variables that affect a student's first experiences with making. I hope to contribute to the existing guidelines for maker educators and offer a list of specific recommendations for how they might support new makers from a wide variety of backgrounds.

Literature Review

Can making be taught?

The Maker Movement as envisioned by Maker Media did not begin as a movement for children (Dougherty, 2016, p. 173). Though it has become a popular educational trend in recent years, it found its start in the garages and machine shops of adult men, an origin that has profoundly impacted its spread. Men like Dale Dougherty, the man considered to be the father of the Maker Movement, are now influential voices on progressive education. People see these older makers, typically self-identified autodidacts and tinkerers, as the epitome of successful 21st century learners and doers. While many educational makerspaces try to follow these examples and give students free reign to explore and work on their own maker projects, even Dougherty himself recognizes the value in a structure (Dougherty, 2016, p. 189).

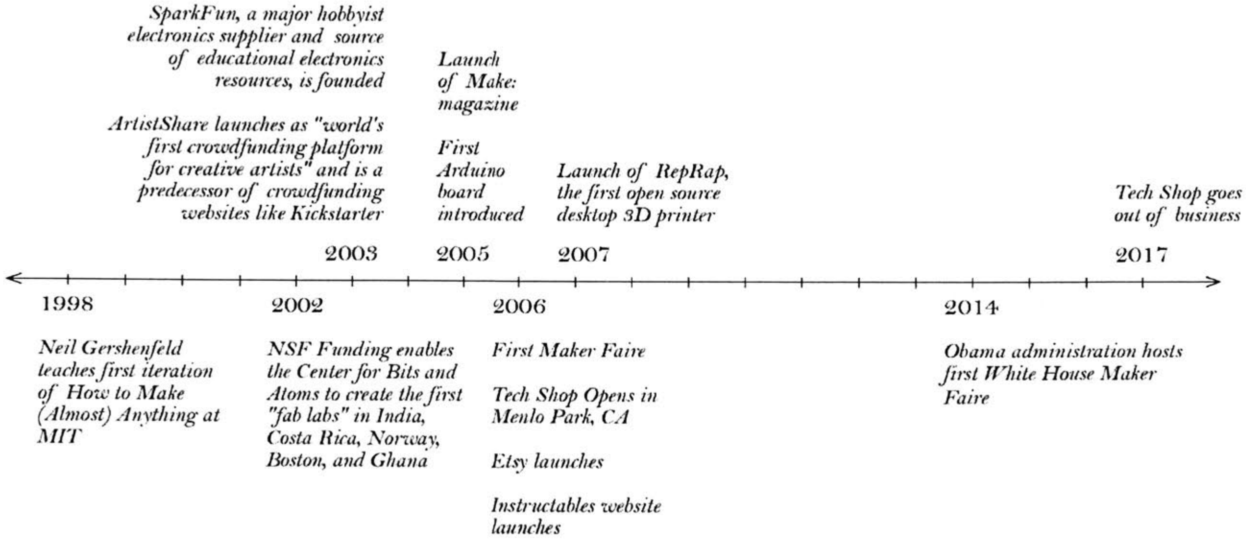

Figure 1: Timeline of Maker Movement

Equity-focused researchers argue for "explicit attention to pedagogical philosophies and practices", questioning the glorification of unguided tinkering which only suits autodidacts (typically white, middle-class boys) while neglecting other students who may struggle (Vossoughi, Hooper, & Escudé, 2016, p. 219). Schools do not expect students to become experts in math or science without the guidance of teachers, so why expect this in making? Beyond conveying new skills and concepts, teachers provide feedback that helps students deepen their technical understanding and gain social-emotional skills needed to succeed in open-ended maker projects and future careers.

The quintessential interest-driven maker project, perhaps with a prescribed problem or constraints, is what Dougherty calls an "open project", and he considers it a sort of "nirvana" for makers that all educational contexts should strive towards (2016, p. 189). But two other types of projects, directed and guided projects, also play a part in reaching that nirvana for many types of learners. Directed projects involve exactly replicating a teacher's actions and serve mainly a training role, for introducing dangerous machines or techniques with a single efficient and/or safe procedure. Guided projects include a set of instructions, but require a mixture of methodical work and individual interpretation and troubleshooting, creating deeper engagement with new concepts.

One example of the value of guided projects is the engineering course at the Lab School in Virginia, where students fabricate kits to use in other courses. For one assignment, students fabricated kits based on a historically important motor, then brought the kits to their physics class to assemble, calibrate, and measure the motor and study electricity in a hands-on way (Bull, Haj-Hariri, Atkins, & Moran, 2015, p. 46). This process helps students understand the connections between disciplines and gives them more ownership over experiments and projects in their core classes. But perhaps most importantly, it teaches them valuable skills like "numeracy, collaboration, and problem solving, as well as appreciation for scale and estimation, and an ability to visualize in three dimensions", most of which are vital skills across several disciplines (p.48). While the Lab School has yet to realize their original goal of testing, refining, and then sharing the kit plans with other schools, they have impacted the individual students involved in the program. Despite not having quite the same level of ownership as a student who designed their own open project, the students who fabricated the motor kits were more confident and willing to take on leadership roles when using them in their science class (p.46). This result suggests that temporarily separating exercises in making from exercises in design can help scaffold students as they gradually gain the confidence needed to initiate their own projects.

Should making be taught?

An important and often unaddressed question facing educators is what specifically students should gain from their making experiences. Most research on the learning outcomes of making start from the typical inventory of a makerspace and derive possible learning outcomes from the tools and activities available. Taylor offers a review of such research, focusing mainly on a survey of makerspaces done in 2015. In the survey, makerspace directors were asked to relate their space to various contemporary movements and skills in education. Most unsurprisingly chose "STEM", but other initiatives including "Media Education", "21st Century Community Learning Centers", and "Next Generation Science Standards" were identified in roughly half of the spaces. A notable detail emerges in the data as well. All of the respondents were familiar with STEM and could state whether they used STEM in their space, but roughly a third of respondents were unfamiliar with Media Education, 21 CCLC, and NGSS (Taylor, 2016, p. 6). The unfamiliarity with these other learning approaches suggests a need for further instruction for makerspace directors so that they can recognize potential learning outcomes in their spaces.

Taylor also describes the alignment of makerspaces with 21st century skills such as creativity, collaboration, critical thinking, problem solving, adaptability, and initiative. He lists all but "critical thinking" as being used multiple times per week in most makerspaces. More autonomous makers think critically nearly every time they approach a project, whether in terms of design, structure, or the safest and most efficient way to use a tool. The lack of critical thinking in youth-oriented makerspaces could signal an overemphasis on procedure rather than deeper instruction on how the tools actually work and how to manipulate them to achieve specific goals.

A possible solution to the lack of critical thinking in makerspaces is a shift in focus from "making" to "design". Chris Anderson claims that "desktop changes everything" (2012, p. 55), by which he means that easy access to machines empowers users to design what they want, when they want it. He cites the desktop printer as an example of this phenomena, recounting how users slowly overcame initial challenges and costs in a way that will likely be echoed by users of 3D printers. Users will soon need to learn CAD and design skills just as they learned word processing skills in prior decades. Anderson is, however, careful to point out that we should not simply produce things because we are technologically capable. Many 3D models now free to download online could be direct descendants of what he calls the "dog's breakfast of typefaces" that sprung forth when desktop printers became mainstream (Anderson, 2012, p. 59).

But unlike the slew of word processing software that will do an acceptable job handling kerning, line breaks, and font choices for the average user, there is no software currently that will do the work of a product designer. The design process is more akin to writing, something we spend over a decade trying to teach to students, and which can only be mastered little by little, perhaps with the aid of a piece of software that helps with the more technical details. Anderson claims that "we are all designers now", and argues that "it's time to get good at it" (Anderson, 2012, p. 59). Whether or not 3D printers become as ubiquitous as 2D printers, students today have an unprecedented number of opportunities to use design skills.

Design and making projects have become a valuable way to network and catch the attention of universities and future employers. Some universities, such as MIT, are now accepting maker portfolios as an optional part of their application process. But beyond these more formal channels, students who publish a portfolio documenting their process and products are able to connect online with others doing similar work and demonstrate their process and skills in a tangible way (Dougherty, 2016, p.197). Even elementary-level guided projects like designing and CNC cutting paper airplanes or mini skateboard ramps offer students a chance to demonstrate their understanding of math, science, and design concepts in a concrete way (Chui, Bull, Berry III, & Kjellstrom, 2013, p. 56).

Beyond trying to impress colleges and employers, maker projects offer a way for students, parents, and teachers to visualize and discuss concepts together. Maker education is often related to constructivism, a theory stating that students learn best by constructing their own knowledge rather than being treated as empty vessels who receive knowledge from others. An even more relevant theory is constructionism, a later theory that builds upon the idea of constructivism by arguing that children should construct actual things (whether digital or physical) to help them construct knowledge. By physically constructing things, students can both deepen their understanding and explain it. In cases like the paper airplanes or skateboard ramps, students were able to understand errors in their thinking or design only once they produced a physical model. Teachers also used these models to observe and discuss student thought processes to help them target errors in thinking (Chui, Bull, Berry III, & Kjellstrom, 2013, p. 58). Though literature so far focuses mainly on STEM-related projects, maker projects could potentially serve a similar clarification and assessment function in humanities subjects.

How should making be taught?

Despite the value of introducing digital fabrication in schools, many problems still need to be addressed. The technology is expensive, limiting most schools to only one or two machines and therefore inhibiting projects with large groups of students. Most schools are still unsure about how to integrate the technology into existing physical and procedural structures. Perhaps most importantly, teacher training remains a problem, as even relatively simple machines require some knowledge of CAD skills to enable original work. Many schools feel pressured to jump directly to 3D printing, but larger and less wealthy schools can often benefit more from getting several cheaper machines to allow multiple teachers to use them at once.

To effectively prioritize making tools and practices when faced with limited time and budget, educators must focus on the needs of their specific students. For instructors in Brazil, Paulo Blikstein's FabLearn is the ideal model, as it focuses on democratizing making and using it as a tool to teach design and engineering, much in the same way that Seymour Papert designed Logo to teach mathematics. Other models, particularly those proliferated by Neil Gershenfeld's Fab Foundation and Dale Dougherty's Maker Media, place too much emphasis on the archetypal hacker as a maker instead of trying to make making accessible to all students. Barbosa e Silva & Merkle describe such hacker-focused rhetoric as the "Californian ideology", which often fails to recognize that technology is inherently ideological (Barbosa e Silva & Merkle, 2017, p. 115). They instead relate the Maker Movement to the Brazilian ideology of Vieira Pinto, who thinks of computers as a human creation made in our own image. This ideology demands a more active approach to technology, using it as a way to both express and understand ourselves. Though the authors are primarily motivated by addressing the role of making in Brazil, their arguments ring true for all educational contexts outside of the Silicon Valley bubble. For example, they found that students in rural schools tended to benefit more from robotics lessons, as they do not even have access to computers at home, and must challenge themselves to learn technology from scratch, becoming more confident as a result.

This confidence is what Dougherty calls "maker empowerment", or the ability to see oneself as someone able to solve problems and create change through making. It is a valuable perspective that leads to higher rates of graduation and career success, but more importantly to greater happiness and self-confidence (2016, p. 204). Maker empowerment is a worthwhile target for every student, but only a select few might have it when they first enter a makerspace. The ubiquity of hacker culture often manifests itself in schools as middle-class boys with STEM backgrounds taking the lead on a project or charging forward with individual work. This leaves girls and lower-income students, who are often newer to making, with more basic tasks or uncertainty about how to join in, and they often leave discouraged and less confident in their skills than when they arrived (Blikstein & Worsley, 2016, p. 71).

Before developing a maker education program, educators should perform "critical analyses of educational injustice", a phrase which refers to systems of oppression like the school-to-prison pipeline and test-score-based funding that disproportionately impact students of color (Vossoughi, Hooper, & Escudé, 2016, p. 215). They should also consider "historicized approaches to making as cross-cultural activity", namely the making practices that women, people of color, people from low-income backgrounds have engaged in for generations. These practices span from sewing children's clothes when families cannot afford to purchase them to using cheap DIY methods to repair electronics, and maker educators should invite students to share and take pride in these practices. Careful consideration of both the disadvantages and the wealth of untapped knowledge in a student's background is vital to helping young makers feel welcome and empowered.

Nichole Pinkard created the Digital Youth Divas program with these principles in mind. The program focuses on a series of projects that mix design with electronics and coding. Each project also includes a digital narrative that presents stories of girls in a similar context facing and overcoming challenges. She employs young female mentors without computer science backgrounds to help the girls learn and to serve as role models. The program also encourages community, welcoming moms to work on projects with their daughters. By directly tackling problems like the lack of representation for young women of color in computer science and using assets like multigenerational crafting practices, Pinkard provides the atmosphere her students need to feel empowered (Blikstein et al., 2016).

While different groups of students will vary, instructors need to start from the notion that every student brings a unique mindset and set of emotional needs into the space. Too often, making can be divorced from the students themselves and instead become just a manifestation of STEM. In fact, making is a creative process and a way to explore and share oneself, a fact which projects should not neglect for the sake of transmitting technical knowledge. The notion that "technology is used to make the human more human" is a unique one that could be considered the opposite of a lot of rhetoric in the United States (Barbosa e Silva & Merkle, 2017, p. 126). Focusing making on STEM and "products" detracts from valuable learning possibilities in favor of economic value. Educators should sustain "ongoing inquiry into the sociopolitical values and purposes of making" and call attention to the military and tech industry influence over the maker movement (Vossoughi et al., 2016, p. 224). While grant money often flows towards STEM-focused projects, it is important to recognize and address this influence.

But how do we bring back the human element in an increasingly STEM-driven world? Perhaps the best advice can be found not in the speeches of today's technology superstars, but instead in the writings of the last century's great educational theorists. Educators throughout the past century have debated a number of theories of learning, and while they have no consensus over which best describes how students actually learn, they can agree that most theories offer valuable advice about how to improve teaching. Four of the most popular theories are cognitivism, constructivism, constructionism, and connectivism. Cognitivism posits that student brains are highly technical, and we can tailor instruction to more efficiently target positive learning outcomes. Certain cognitivist researchers go so far as to argue that students have a limited cognitive load that they can handle at once, and that teachers should try to reduce unnecessary load in learning activities. Strategies they suggest include completion problems, worked examples, goal-free problems, avoiding split attention, mixing visual and auditory modalities, and avoiding redundancy (van Merriënboer & Sweller, 2005). While most cognitivist writings target highly prescribed coursework like arithmetic, the idea of minimizing unnecessary struggling is useful in makerspaces. Worked examples in particular can be useful, as demonstrations typically help students understand a new process more quickly than if it is just verbally explained or if students must figure it out themselves.

Constructivism refers to a range of theories that suggest that knowledge is constructed rather than simply delivered from an outside source. Phillips provides a brief overview of major theorists and concepts in constructivism and organizes them along two axes. The first axis is a spectrum from a focus on societal construction of shared knowledge to a focus on individual construction of personal knowledge, with many theorists falling somewhere in the middle. This notion is particularly interesting in a makerspace context, as many makerspaces tend to emphasize individual autonomy and personal projects, when in fact a lot of successful makerspaces rely heavily on shared knowledge of best practices for working with different tools and materials. The second axis addresses to what extent the theorist considers knowledge to be "made" rather than "discovered" (Phillips, 1995). This distinction is often compared to the difference between science and engineering, though in fact both require a mixture of “discovered” knowledge about materials and forces and “made” knowledge about how to best harness them to achieve a goal. Makers must also leverage this combination in order to successfully manipulate materials, machines, and tools to achieve a goal. While the inconsistency among theories of constructivism can make it difficult to apply in practice, Phillips’ axes offer interesting lenses for considering what types of knowledge exist in makerspaces. To successfully instruct student makers, educators must consider both personal and shared knowledge, and both “made” and “discovered” knowledge.

Constructionism is a descendant of constructivism that focuses more specifically on constructing physical or digital things as a way of constructing knowledge. This theory is typically associated with Seymour Papert, who does not offer a clear definition but instead describes a series of situations and ideas that hint at his own understanding of constructionism, expecting, to some degree, that the reader will construct their own definition and that it would be against constructionist beliefs entirely to simply hand the reader a definition. He describes the ideal learning environment as one with "time to think, to dream, to gaze, to get a new idea and try it and drop it or persist, time to talk, to see other people's work and their reaction to yours" (Papert & Harel, 1991). His own creation, the LOGO programming language and supporting "turtles", offers to some extent this exploratory context, but his successor, Mitch Resnick, takes the idea even further through the programming language Scratch.

Resnick's research group, the MIT Media Lab Lifelong Kindergarten group, articulates this ideal environment with what they call the "Four P's of Creative Learning", namely projects, passion, peers, and play (2017). These four P's are vital aspects of making, with projects and passion being defining traits of the maker movement from the start and peers and play becoming increasingly emphasized. Though the words themselves are somewhat childlike, they hint at the processes used by engineers and designers to invent new products and systems. "Projects" are key to most explanations of constructionism, as constructionist learning demands hands-on work in pursuit of a goal, expecting that learners will construct knowledge as they construct their project. "Passion" deals more with motivation, an increasingly emphasized aspect of successful learning environments. While students can learn in a behaviorist or cognitivist fashion without any emotional connection to their work, they cannot be expected to actively construct knowledge without a personal attachment to their work. "Peers" offer a different sort of depth and cross-pollination that cannot be accomplished by a solo learner. Though not strictly necessary for learning, peers offer a source of accountability and encouragement, while also providing useful tips and unique perspectives, all of which are vital ingredients for long-term success in challenging learning environments. Finally, the word "play" suggests a mindset that can make or break a constructivist learning environment. While the trendy emphasis on "design thinking" often promotes "failure" as a way to learn, the word "play" achieves the same goal with a much more positive connotation. Play in learning refers to activities that are undertaken without a clear understanding of the outcome, designed to simply explore a learning space and see what happens. Play can spark a new project idea, an understanding of the way something works, or simply an increased awareness of one's own thought processes. In makerspaces, play often looks like re-mixing others' designs or engaging in small tests of materials before undertaking a larger project. While at least one of projects, passion, peers, and play is found in nearly every makerspace, the spaces that create lifelong makers are the ones that support a mix of all four.

Connectivism is a theory of learning designed for the 21st century. It emphasizes relationships between people, both those maintained personally and those virtually created by the internet. Siemens describes learning as "actionable knowledge" which can "reside outside of ourselves" and claims that "the connections that enable us to learn more are more important than our current state of knowing", suggesting that constructing relationships is infinitely more valuable than learning facts (2004). Others bring a more ideological perspective to connectivism, arguing that "connected learning centers on an equity agenda of deploying new media to reach and enable youth who otherwise lack access to opportunity" (Ito et al., 2013). Regardless of whether the theory is expressed in a practical or ideological fashion, it hints at the tendency of technology to make knowledge of facts obsolete, favoring instead a knowledge of where to find those facts. The idea of connectivism is interesting in relation to making, as it calls into question a number of ethical dilemmas related to sharing knowledge and ideas in inventive and creative work. However, ethics aside, it does provide a way to prioritize content delivery in terms of making, as the internet provides resources for a variety of tricks and techniques that students may later want to learn.

Perhaps the best synthesis of the most relevant parts of each learning theory is Seymour Papert's idea of "hard fun", which requires learners to grapple with difficult material to achieve a goal that interests them (Blikstein and Worsley, 2016). Making as an educational field has the distinct advantage of being interest-driven and focused on physically constructing things as way to learn, but educators must be careful to tailor the difficulty level and amount of social interaction students receive to keep the difficulty level in check and ensure that students remain motivated to continue. Blikstein and Worsley also mention that very young children should use materials built for them, rather than struggling with more complex technology like Arduinos that have a steep learning curve for even the simplest outcomes.

Educators should also invoke community and family, as Rafranz Davis does in the Lufkin Independent School District. After experimenting with expensive technologies like Little Bits, she found more success with cheaper items like paper circuits that students could take home and share with their families. Students benefited most when their work occurred both in and out of school, and her district also motivated students by letting them bring their after school hobbies like Minecraft into an educational context in supported and productive ways. Peers also play a major part in promoting motivation. Pinkard highlighted showcasing as a valuable element of makerspaces, claiming that students can progress much more quickly if they see what other students do and believe that they can do those things as well (Blikstein et al., 2016).

Above all, we need to stop imposing our STEM-focused, middle class, White American definitions of making upon students. Paulo Blikstein, director of the Transformative Learning Technologies Lab at Stanford, emphasizes the distinction between equity and sameness when he discusses making (Blikstein et al., 2016). For him, the children who need and deserve making the most are the students who are not motivated to do well in school and go to college. What students like that need is not an assigned space in the STEM pipeline, but exposure to powerful ideas and renewed excitement for school. By treating students of color as "targets of intervention rather than sources of deep knowledge and skill" and comparing them to dominant communities who we consider "ahead, with something to teach or offer rather than something to learn", we deny both groups an opportunity to learn and grow (Vossoughi et al., 2016, p. 212). True maker empowerment and deep learning will only occur once we recognize that young makers are also students and humans and we give them the support, motivation, and recognition they deserve.

Interview Findings -- Creativity is Scary; Role Models are Vital; The best Activities Follow You Home

The purpose of this thesis is to study the ways in which introductory activities can set the tone for a student's entire maker education. I reviewed literature, conducted interviews, and completed user testing to develop an introductory maker workshop and a set of guidelines for adapting the maker workshop to different groups of students.

I began the research process with the theory that pedagogical interventions could effectively boost student confidence and motivation in maker activities. To this end, the first step was identifying an appropriate set of pedagogical interventions, including exploring existing maker educational practices to identify a set of problems with existing programs as well as a set of best practices to inform my own lesson planning. The interviews helped me identify pedagogical approaches currently in use to tackle issues I identified in the literature as well as opportunities to better align practice with theory. Next, I designed lesson plans and a student survey based on my findings. Then, I ran the workshops and administered the survey at MIT Spark to test my ideas, and then used my findings to drive a final literature review and analysis phase.

Interviews

I conducted interviews with maker educators to collect their opinions on the current state of introductory maker education. I reached out to nine maker educators in the Boston area, of whom four responded and agreed to meet with me. I set up 1-2 hour conversations with each of them to discuss their space, their pedagogical approach, and their thoughts on maker education in general. In shaping these conversations, I considered a list of three general factors at play in introductory activities to determine what I might test in my own workshop. As I interviewed maker educators, I made a point of asking questions related to these three topics to see which had the most impact on students as well as which offered the best opportunities for change. The themes I identified initially, based on my own experiences and my initial literature review, were the following:

1. **Gendered activities**

   How do introductory projects that are stereotypically associated with a certain gender affect the extent to which students of different genders identify as "makers" and choose to continue in maker-related activities? I could test this by using stereotypically gendered introductory activities with different groups (such as making vinyl-cut jewelry vs. making a paper football field vs. a gender-neutral activity like making geometrically-interesting boxes).

2. **Abundance of materials**

   To what extent do material constraints stimulate creativity and complexity in student work? I could test this by varying the types of materials and colors of materials given to each group. Creativity and complexity are difficult measures to evaluate, however, so I would need to find a way to make that more quantifiable to compare the different groups.

3. **Instructional style**

   How do varying styles of instruction impact a student's comfort and confidence with making? To test this, I would create different introductory lessons (perhaps a demo, a hands-on task, and written instructions) and then give students time to work on a project. I would primarily rely on pre- and post-surveys as well as observations of student interactions to provide data for comparison in this case.

After interviewing maker educators, I was confident that of the three variables I had identified, instructional style offered the most opportunity for an effective intervention. The educators I spoke with were already using projects that could be reasonably called "gender neutral" in order to avoid alienating certain groups of students, and they were all significantly underfunded and noted the importance of keeping materials cheap and accessible. Their pedagogical approaches varied significantly, however, suggesting a lack of shared best practices within the maker education community.

There is a significant amount of variation between spaces in the types of programs they run, who they employ to run them, and who attends them. For example, a space in a museum relied on one paid adult to facilitate a drop-in program where participants rarely stay longer than an hour while another space in a community center had a small army of teens, presumably paid much less than the single adult, supervising both drop-in hours during the school year and longer-format summer programs, with a much longer average stay as well as a more local focus. The programming in the former focused on a single activity each week, assuming that many visitors lacked experience with making but were eager to learn in a structured way whereas the programming in the latter was much more freeform, mixing structured activities for learning, particularly during the summer program, with open making hours when the teen "Fab Stewards" helped visitors create projects of their choosing. The variations often aligned with the social and economic context of the space, but overall, the different spaces shared a goal of inspiring young people to develop maker skills and a maker mindset that they can bring home with them and apply to problems in their life. This mindset could be sparked through a 20-minute activity or developed over the course of a multi-week summer program, but students, regardless of background, tend to have similar needs and obstacles that influence maker pedagogy. Through my conversations with maker educators, I noticed three principles that were consistently at play as they designed and facilitated activities.

Principle 1: Creativity is scary

I have yet to meet a successful maker educator who still starts students off with unstructured making time. One fab lab supervisor told me that she used to give students full freedom, but none of them progressed much beyond downloading and 3D printing keychains. Educational theorist Paulo Freire would most likely be unsurprised by this result, given his claims that novices often lack the "intellectual discipline that gets the learner to confront difficulty head on, rather than turn away in the face of fear" (English and Stengel, 2010, p. 538). This fab lab supervisor switched to a method that fosters the sort of intellectual discipline Freire mentions. She required students to first examine and reproduce an existing object, then use that object as a jumping off point for further guided iteration until they were ready to improvise their own designs. Another instructor told me about how reluctant older students and adults are to just jump in to an activity and start creating things. She often has to give them specific technical challenges to guide them, such as "see if you can build a structure that allows these pieces to move in this way" before they will actually pick up materials and begin to build things.

For many students, this aversion to creativity stems from a fundamental fear of the unknown. Rousseau argues that "there is a strong correlation between the absence of certain experiences in one's childhood and the fears one has as an adult" (English and Stengel, 2010, pp. 526-527). If someone did not engage in much creative work as a child, they may be particularly averse to trying to create an original sculpture, for example, as an adult. Some students "may become so preoccupied with academically letting themselves or others down that they actually strive to avoid failure in situations involving achievements (such as not showing up for a test), instead of intentionally pursuing successful outcomes (by studying and taking the test)" (Bledsoe & Baskin, 2014, p. 33). In voluntary activities such as drop-in making hours, it is therefore only natural that older students and adults with an ingrained fear of failure will simply refuse to participate.

In these cases, tactics that relate the task at hand to more familiar practices, like solving a puzzle rather than creating a work of art, can be particularly helpful. But educational researchers caution against anything that could be considered "coddling". Rousseau finds that too much consistency can make students "increasingly vulnerable to and more frightened of any type of change in circumstances" (English and Stengel, 2010, p. 527). Maker educators, particularly in settings where participation is completely voluntary, must therefore walk a fine line between making learners feel supported and pushing them outside of their comfort zones. For younger students, Dewey's approach might be most successful. He argues that discomfort in the face of the unknown is just an affect that can be turned into one of two more impactful emotions: fear or interest. It is vitally important for instructors to "suspend a learner's affective responses so that they are not named, enacted, and thereby habituated as fear" (English and Stengel, 2010, p. 534) and encourage the student to find possibilities for interest instead.

With older students who have already developed fear of creative work, Freire may offer a more constructive tactic. He notes the usefulness of social interactions in overcoming fear. When student fear stems directly from a judgment of their own ability, "our focus needs to shift from individual assessments of lack and failure to intersubjective social understandings and opportunities for learning" (English and Stengel, 2010, p. 537). Simply engaging in group work that allows other students to share more positive perspectives on a task can help students shift their own perspectives from fear to interest. A maker educator who often works with families noted this tendency with siblings. While younger students are often look up to their older siblings, older siblings can also learn from their younger siblings who more readily take an interest in an unfamiliar activity.

Principle 2: Role models are vital

As with most STEM-related fields, the makers most commonly in the public eye are middle-aged white males. Economic privilege also plays a role, offering many middle class students the opportunity to do STEM and maker enrichment activities or even simply build things at home with their parents. For many other students, however, the idea of being a maker is a foreign and often intimidating concept. Particularly with low income students of color, maker educators have found mentorship programs incredible valuable. One makerspace coordinator I spoke with has a unique program that recruits paid teen "fab stewards" to instruct younger students. New fab stewards or visitors during open making hours are introduced to making by these more experienced fab stewards, students who look like them and remember being in their shoes. Though the fab stewards have formal machine shop and teaching training to ensure they do their jobs well, they are still high school students and share the background of many visitors to the space.

Even in more privileged settings like museum makerspaces, young students often look to their older siblings, teens they see around them, or their parents for guidance. If harnessed correctly, this influence can inspire young students to try new things and adopt a maker identity, but such influence can backfire. An instructor I spoke to recalled instances when older siblings or parents would refuse to partake in an activity and just sit on their phones instead, and the younger kids would then be less excited to do the activity. She also noted that while young students can often be motivated and inspired to try an activity, older students will not even enter the space if there are only young kids in the room. She works hard to get parents, particularly mothers, and older students to try things, knowing that they will attract other participants of all ages, but it can often be an uphill battle.

While engaging older siblings and parents can be a valuable tactic in public makerspaces, it is not often possible in a school settings. However, educators can still act as role models, bring other role models into the space, and prepare students to eventually become role models for other students. In the context of my Spark workshop, I could act as a role model by mentioning my own challenges during my early days of making, even mentioning that I was much older than them when I learned. I also enabled future interactions with role models by sharing a list of public makerspaces in the area for them to explore later, potentially with their family or friends.

Principle 3: The best activities follow you home

While expensive maker kits and electronics supplies may seem exciting, they are rarely a worthwhile investment for makerspaces serving diverse groups of students. With limited funds available to K-12 makerspaces, it is almost always better to invest in machines and hand tools and stick to cheaper materials and bulk electronics components. The spaces I visited had open walk-in hours and often had a wide array of people using the space for varying lengths of time, so it was important to have enough materials for many people and to give them materials that they could take home with them afterwards.

Being able to bring home a project is vital for two main reasons. The first is the fact that parents and siblings can offer direct encouragement and feedback when they see the student's work firsthand. Parents and older siblings are often the main role model's in a young student's life, and their involvement in projects, even simply through words of support, can be the inspiration a student needs to keep going. The second reason is the physical act of bringing making out of the makerspace. By taking their work home with them, students gain the opportunity to keep tinkering with their projects and expanding on them outside of the makerspace. This opportunity encourages further interest-driven exploration and cultivates lifelong learning practices. Seeing the product of their work also reminds them that they are capable of making things and can inspire them to create solutions to everyday problems they may encounter.

Finding the right materials that are cheap enough but also interesting for students can be challenging. Arduinos can be great reusable tools for learning electronics, but they are too expensive to give out at a drop-in activity. Bulk micro-processors offer the computational power of an Arduino for a fraction of the cost, but they have a steeper learning curve and require users to spend time soldering. Paper circuits with copper tape offer a low cost way to teach basic electronics, but are limited in their capabilities and may not interest older students as much. Every scenario requires a decent amount of consideration and calibration to find the right materials for the target audience.

For my workshop, I chose to use cardstock as a way to keep costs incredibly low and allow students to focus on more difficult digital concepts instead of having to work with an unfamiliar material. At the same time, the fact that the cardstock is being used to create a lantern offers the potential for more complex iterations should they use to explore more at home. While they will walk out with a single-layer paper lantern or two and an LED tea-light to illuminate it, they could decide to set up the lantern over an LED controlled by a light sensor and an Arduino. They could also use the vinyl cut model as a prototype and laser cut a larger, more durable lantern out of colored acrylic. These two possibilities require access to additional resources later on and demand a certain amount of learning, but even with the simplest available resources, students could still make a series of copycat lanterns with paper and scissors or create a wire-hanger mobile with the lanterns to hang in their room. If nothing else, they'll have an elegant lantern to look at as reminder of what is possible with a sheet of paper and a bit of design work.

Workshop -- Testing How to Teach Making

My primary testing occurred in March of 2018 during Spark program, a two-day program organized by the MIT Educational Studies Program (ESP) for seventh and eighth grade students to take one-off classes taught by MIT students and affiliates. The program's motto is "teach anything, learn anything", so it tends to attract both teachers and students with diverse backgrounds and interests, though I acknowledge that because students have to provide their own transportation and housing, the program does limit itself to Boston-area students and students from wealthier families who can afford the trip.

During Spark, I ran four sections of the same class called "Introduction to Digital Fabrication with Paper Lanterns". Each section was two hours in length and had space for eight students. When I actually ran the sections, two ended up with six students, one had eight, and one had nine. Of the 29 total students, 12 were female and 17 were male. Enrollment was determined by a combination of student preference and an enrollment lottery facilitated by ESP. I had no influence on class enrollment other than setting a cap for the number of students per section. From the student's perspective, the four sections were identical except for their time and location (one section was scheduled for a different room, as the location was outside of my control). Of the four sections, the first and fourth acted as a control, while the second and third included an experimental intervention. These designations were chosen to avoid a time-of-day bias and a Saturday vs. Sunday bias, as the program was full-day over two days.

The overall lesson plan used an equity-focused pedagogy, student motivation, maker education in general, and student identity. Due to the complex nature of education and student needs, this approach could not accurately be described as a randomized controlled trial, and I chose to collect mainly qualitative data to compare the two versions of the workshop. Even within a simple two-hour workshop, the pedagogical variation space is incredibly vast. However, the goal was to observe student response to a carefully selected set of pedagogical interventions, so subjective measures of students' changing attitudes towards making offered a reasonable way to assess success.

Starting from the beginning of the activity, there are several key choices that can affect a student's experience. I could explain the process in a variety of ways: using a vague description of the overall phases of the process, using a detailed description of the exact actions a student must take to complete each step, or actually demonstrating the full process with a simple worked example. Along with this explanation, I could also choose whether or not to contextualize the exercise by explaining how the skills used in the activity could transfer to more complicated products or fabrication techniques.

After this short but necessary piece of direct instruction, I could then offer one of three main entry-points into the primary activity. The first, which helps students acquire technical skills while postponing the more challenging creative aspects of the project, is to have all the students imitate an existing product. The second, which emphasizes creativity while postponing the technical aspects, is to have students sketch and discuss their ideas without using the software so they can develop their concepts before learning the technical aspects. The third, which is often used in maker activities, requires students to exercise creativity while simultaneously learning the technical skills by simply diving into the activity using the software and developing their own ideas simultaneously. While this third method may appear the most efficient, some might argue that it involves an unnecessarily high cognitive load and therefore may discourage and overwork the students.

There are additional variables at play during the activity itself. The design process is traditionally composed of some sort of brainstorming phase, a series of iterations with intermittent testing and feedback, and finally a finished prototype with some sort of presentation or packaging. In an accelerated program like a two-hour workshop, some of these elements will most likely be sacrificed for the sake of time. The choice of what to sacrifice depends significantly on the goals of the workshop. In a traditional design setting, iteration and feedback are key to developing a good design, but for an introductory activity with a goal of developing a maker identity more than a finished product, these steps may be sacrificed. The number of iterations in this case should mainly relate to the amount and type of feedback given. The feedback could come from the instructors, the other students, or both, and each comes with a set of advantages and disadvantages. The instructors are capable of giving targeted feedback that is tailored to a student's comfort level, but are limited in number and thus must either have a set of time for midpoint presentations and feedback (a time-consuming proposition) or must visit each student individually as they work, which could result in students being reached at an inopportune moment. Peer feedback is a bit more flexible timing-wise, as students can pair up as they finish, but peers are less likely to be able to tailor feedback to other student's needs, and are limited as novices in the quality of advice they can give. Peer feedback also increases the risk of peer comparison, which can result in less experienced students feeling discouraged about their work.

Following the activity, different styles of wrap-up can affect a student's emotional response to the workshop. If I chose to have students present their work, some students would experience an increased sense of accomplishment, while other students may feel inferior if they compare their work to that of their peers. Giving feedback at this point could also inspire further exploration after the workshop, but it could be poorly received if students are tired and just want to celebrate being done. The end of the workshop is also another opportune time to contextualize the activity if that was not done at the beginning, and explanation of the implications of student work and potential next steps could inspire future exploration.

I made many of these choices for the sake of time, including limiting the number of iterations to one or maybe two if a student finishes early, eliminating any sort of presentation at the end, and taking the time to have students learn the process by replicating an existing process. To decrease cognitive load during the design phase, I chose to limit the students' access to a computer to only web browsing for research purposes, encouraging them to think and sketch instead. I found the question of feedback and peer collaboration to be the most promising, so I chose to vary the role of peers between groups.

In all four sections, I started by giving the students a short presentation on the project, the purposes of vinyl cutters, how vinyl cutters compare to more advanced digital fabrication technology, and some examples of lanterns that were within the scope of what they could do in the workshop. Following this presentation and before I introduced the software and demonstrated the machine itself, I gave them time to generate ideas. In all sections, I gave them a list of questions to guide their thinking (Appendix B). In the two control sections, the students received the list along with scratch paper and pencils and were told to take time to think, answer the questions, and generate ideas, and that they could feel free to sketch, fold, or otherwise manipulate the scratch paper to help them figure out ideas. In the experimental sections, the students were first organized into pairs (and one group of three in the section with an odd number of students) and instructed to discuss possible ideas with their partner(s), taking turns asking some or all of the questions.

I allowed the brainstorming to take place for ten to fifteen minutes or until a few of the students had reached a stopping point and looked eager to start learning the software. At that point, I interrupted the brainstorming and ran a brief demonstration of the entire design process. Working solely in Silhouette studio, I inserted an image file that I had downloaded from the internet, demonstrated the use of the trace tool to convert the image into cuttable lines, added a rectangle to form the based of the lantern, and merged the shapes to make a single piece. I then demonstrated the use of dashed lines to create folds and walked through the design to make sure they could identify positive vs. negative space and cut vs. fold lines. Finally, I set the material settings and cut the design on a piece of cardstock using the vinyl cutter. After the students watched the machine run (the designs I chose were all very quick to cut), I told them they could either keep sketching and brainstorming or move on to the software.

From that point forward, my instructions did not vary between sections. My role and my co-teacher's role for the rest of the session was to simply answer questions and provide assistance while cutting, and the only class-wide information I gave was updates on the amount of time left and comments to fix things like the paper size in the software which I had noticed multiple students forgetting. The students could use the rest of the time to design their lanterns in Silhouette studio on the computer lab computers, send the file to my computer, and cut from my computer using the vinyl cutter. Students were welcome to cut multiple times or use multiple sheets of paper if they chose. They were also welcome to ask any questions of one another or of myself and my co-teacher. Due to the time constraint of the workshop and the inevitable technical difficulties students faced, we also allowed them to stay a bit late to finish cutting their designs if they chose.

Control

The first control section took place on Saturday morning at 10 AM. The class consisted of three boys and three girls. The group was fairly quiet at first, except for one white male student who enthusiastically asked questions and expressed the fact that his dad does woodworking, so he already knew about making. During the brainstorming time, students were instructed to think through the questions and sketch ideas on paper as they saw fit. All students were seated at the table in the center of the room, but two students soon asked if they could move to the computers along the wall to look things up. The female student began searching for lanterns to use as inspiration, while the male student began looking up images of specific characters he had in mind. The remaining four students worked quietly on sketches. The boy whose father had previously done woodworking very quickly began sketching an unrolled multi-sided shape. The other boy sketched out a completely original pattern with squiggly lines and star-like shapes. One of the girls started sketching things, but immediately erased her sketches when she was not satisfied. The final girl sat quietly and sketched a couple very small patterns, but when asked about them would shake her head or erase them.

After a couple of the students had finished sketching, I demonstrated the vinyl cutter software and machine use, then let the students started working on the computers. The behaviors I observed during the sketching phase seemed to continue, with the notable exception of the boy who had sketched the original abstract drawing. He had confidently created his sketch, but once exposed to the software proceeded to tell me multiple times that he "was new to this sort of thing". Though he was quiet and seemed somewhat embarrassed about his lack of experience, a bit of verbal reassurance that everyone was new to it and it was a hard thing to master seemed to give him the validation he needed to persist. By the end, he managed to almost perfectly reproduce his sketch in the software using the line drawing tools, and he successfully cut a lantern.

Of the two girls who struggled most during the sketching phase, one seemed more comfortable in the software and successfully traced an image she found online, suggesting that she simply considers herself bad at drawing. The other girl, unfortunately, seemed more hesitant to be creative at all. When I directly asked her about her preferences, she would quickly and confidently respond, but she seemed more resistant to experiment than the other students. In the end, she did not seem to like any of her designs enough to follow through with them to the cutting stage. The other students all managed to finish their designs and cut out a lantern. The lanterns were fairly diverse in their content, but the overall shapes were simple, mainly consisting of cylinders made by rolling the full sheet rather than cutting it into a unique shape.

The second control group took place on Sunday at 3 PM, making it the final class of the weekend for the students who participated. There were six students, of whom four were female and two were male. Like the first control group, they were generally pretty quiet, though there were some off-topic conversations that occurred. After the girls finished cutting, they sat together at the center table and chatted while removing the cut shapes from their lanterns and assembling them. The two boys also interacted, though mainly by showing each other funny pictures online when they were supposed to be working on designing their lanterns in the software. When directly prompted to do so, they would get back on task, but then would quickly return to whatever they were looking at. At no point did it seem like either group was actively discussing their designs and giving each other constructive feedback, though the group of girls did offer one another compliments on their designs.

In terms of the designs themselves, they were generally simple form-wise, though there were a few that branched out beyond a basic cylinder. The patterns were much more personal, including one with a tapir and strands of DNA that a girl made for her mother. A few students with intricate patterns did find it hard to keep track of positive and negative space when they combined multiple shapes in a single design, but with instructor assistance were able to make their designs work as they wanted.

Experimental

The first experimental section took place on Saturday at 1 PM. There were eight students, of whom three were female and five were male. When asked to pair up during the brainstorming activity, everyone paired up based on where they were sitting. The resulting pairs consisted of two girls who walked in together (pair 1), two boys who had both decided to sit in the back (pair 2), a girl and a boy who entered individually and quietly, but sat near one another (pair 3), and two boys who sat near the front, one of whom had come in late (pair 4). When given the prompting questions, pairs 1 and 2 were very chatty and immediately started sketching and sharing their ideas. Pairs 3 and 4 mainly worked alone, but interacted with one another when prompted. Unlike in the control groups, there was very little time when students just sat quietly thinking. The students either talked through their ideas, sat quietly and sketched, or combined the two by illustrating their ideas as they explained them. Pair 2 progressed quite quickly, so I asked them to assist pair 3 with idea generation. They were eager to do so, and they effectively engaged the boy from pair 3 in a conversation about his ideas. The girl from pair 3 mostly sketched on her own, though she was clearly listening in on the conversation between her partner and pair 2.

When told that they could start working on the computers, everyone chose to sit beside their partner except for pair 3, who selected computers on opposite sides of the room. Even during this phase, when there was not any explicit group work to be done, the students were much more talkative and lively than the control groups. My co-teacher and I were constantly moving from student to student to answer questions. Students would typically raise their hand or call one of us over when they encountered a problem, but would help one another when told to do so. After helping one member of a pair with something that everyone had to do, I would typically tell them to teach their partner so I could avoid repeating myself. I spent a larger portion of time with one of the boys from group 3, as he was clearly very inexperienced with computers. I quickly noticed that he got confused by a lot of my explanations and worked more slowly than the others, so I focused more time and energy on helping him learn computer basics, even writing the vital shortcuts “ctrl+c = copy”, “ctrl+v = paste”, and “ctrl+z = undo” on a sticky note for him to easily reference. When his mother arrived at the end of class, she echoed his statements that he did not really know how to use a computer, though she clearly did and quickly and easily helped him with the last couple steps of the process. Though he struggled, he was able to cut a lantern in the end, and I later received a follow-up email from his mom saying that he loved the class and it was his favorite of the nine he took. She was also eager to help him find additional resources for him to explore what he learned and thanked me for the list of resources I sent after the class.

Overall, this section was very lively and supportive. Even though multiple students ran out of time and not everyone got a chance to cut their lantern, everyone finished with a successful design. Some of the pairs also waited together for their turn to cut, even staying after class had technically ended. The overall forms of the lanterns were also more varied than in the control sections, including a mixture of cylinders, cubes, and even dodecahedrons.

The second experimental group took place on Sunday morning at 11 AM. It was the largest group, with nine students total, of whom two were female and seven were male. The atmosphere was very similar to that of the other experimental group, though a bit louder due to the larger group. The designs were also particularly successful, with every student finishing their cuts (though again, some stayed late and cut into their lunch break). The students also all had completely unique designs, both in form and pattern. This section was in a different room than the other three, so there was no center table. While this meant that more students used the computers during their brainstorming time as they were right there in front of them, it also meant that the pairs (or groups of three) were seated next to one another for the entire time. The students sketched a lot and talked more during the brainstorming time, but they continued to interact with one another in an on-task way throughout the two hours. It is worth noting that the boys were generally louder than the girls, whether talking to one another or trying to attract an instructor for help, but all of the students were consistently positive and eager to learn.

Survey -- Testing Making and Identity

I designed the survey to include a mixture of Likert-scale questions, multiple choice, and short response questions to elicit a variety of data types and give students the opportunity to express anything I failed to cover. The survey questions were designed to elicit student opinions on who can be a maker, what making is for, and to what extent they personally identify with making. While it was unlikely that these perspectives would change dramatically over a two-hour period, I did split the survey into two parts to ensure that the effects of the workshop on student opinions were captured. The complete text of the survey can be found in Appendix C. Due to the relatively small participation rate for the survey, variation in number of survey questions answered, and the lack of a notable difference between the survey results in the control groups and the experimental groups, I will address the survey data for both groups together.

The survey was administered in two parts: one at the beginning of the workshop as students were arriving and another at the end once students completed their lanterns. A total of nine students completed some part of the survey, and of those six completed both the pre-survey and post-survey. The first part of the survey asks students to rate the extent to which they identify with certain making-related terms on a 5-point Likert scale. The terms were maker, hacker, tinkerer, inventor, engineer, crafter, artist, and designer. In general the students gave relatively average responses to each term, and these responses did not change significantly between the pre and post surveys. The one term with an average rating that did not fall between 2.8 and 3.8 was "hacker", which had an average score of 1.9. On the other hand, "crafter" had the highest score with an average rating of 3.8.

The small sample size made it a comprehensive breakdown by race and gender unreliable, and no female students of color chose to partake in the survey, so I was also unable to analyze the intersection of race and gender in this context. However, I did break the data into a group of male students who did not identify with an underrepresented minority group and a group of students who were either female or belonged to an underrepresented minority. Overall, the two groups had similar scores, with the biggest variation falling under the term "maker", with the female/URM group giving the term an average of 2.8 and the male non-URM group scoring it 3.8. Scores among the various terms, however, differed less in the female/URM group. Their average ratings for each term ranged from 2.2 to 3.5, while the male non-URM group ranged from 1.8 to 3.9. Both groups had the term "hacker" as the lower end of the range and the term "crafter" as the upper end of the range.

Identity	**Maker**	**Hacker**	**Tinkerer**	**Inventor**	**Engineer**	**Crafter**	**Artist**	**Designer**
Female or URM	2.8	2.2	2.8	3.3	3.3	3.5	2.7	3.2
Male, not URM	3.8	1.8	3.2	2.6	3.1	3.9	3.3	3.2

Table 1: Average identity ratings on 5-point Likert scale broken down by gender and underrepresented minority status

The next question asked students to select up to three endings for the sentence "Making gives me a way to…". The options were "solve problems in my own life", "solve problems in the world/other people's lives", "express my thoughts or feelings", "relax and unwind", "learn new technical skills or concepts", "create products I want at a lower cost", and "create customized products/gifts for myself or someone I care about". The mostly popular response overall was "learn new technical skills or concepts", closely followed by "create customized product/gifts for myself or someone I care about". When broken down by gender/URM status, the male non-URM most popular responses stay the same, but for female/URM students, the response "solve problems in my own life" came in slightly ahead of the other two. Solving others' problems and saving money were the least relevant for students regardless of identity.

The following three questions used asked whether students agree with certain statements on a four-point Likert scale. The three statements were "I want to learn more ways to make things using digital fabrication", "I can teach myself new techniques for digital fabrication", and "I can figure out how to digitally fabricate most simple (small, non-electronic) things I want, either by myself or by asking someone I know for help." Everyone either agreed or strongly agreed with "I want to learn more" on the pre-survey, a rating which either increased to strongly agree or stayed the same in the post-survey. For the "I can teach myself" statement, there was a wider range of answers. In the pre-survey, four students disagreed, three agreed, and one strongly agreed. The breakdown of responses by identity can be found in Table 2. The "I can figure out .... most things" statement yielded more positive responses, with six agrees and one disagree in the pre-survey and five agrees and one strongly agree in the post-survey. No student strongly disagreed with any of the statements, so that response category was omitted in Table 2. Where pre-survey and post-survey percentages differ, they are formatted as "pre/post" in the table.

Identity	**I want to learn more...**			**I can teach myself...**			**I can figure out...**		
Response	**Disagree**	**Agree**	**Strongly Agree**	**Disagree**	**Agree**	**Strongly Agree**	**Disagree**	**Agree**	**Strongly Agree**
Female or URM	0%	50%	50%	67%/0%	33%/ 100%	0%	33%/0%	67%/ 100%	0%
Male, not URM	0%	80%	20%	40%/0%	40%/ 75%	20%/ 25%	0%	100%/ 75%	0%/25%

Table 2: Percentage Of Responses To Agreement Statements About Interest, Ability To Self-teach, And Ability To Figure Things Out With Or Without Help, Divided By Identity Groups

The remaining questions were open-ended short response questions. The first, "in a few words, describe the sorts of people you believe digital fabrication is intended for", yielded seven responses in the pre-survey and five in the post-survey. Pre-survey responses were a mixture of comments along the lines of "anyone willing to learn" and "smart people or engineers", plus one male with some making experience already declaring "everyone, that's the point". Post-survey responses were similar, but more students said "everyone" or added "artists" to their "smart people and engineers". The most significant shift was the responses of a black male student, who said "smart people or engineers" in the pre-survey, but changed his response to "anyone with a computer" in the post-survey.

The second item asked, "In a few words, describe the sorts of products you believe digital fabrication is intended to produce". The responses varied, and most students listed several items such as "products relating to technology", "random small things that break", "circuits", "cards", "origami", and more. The post-survey responses tended to be far less specific, with most responses saying "anything", perhaps with small qualifiers like "almost" or "household items".

The remaining questions were solely in the post-survey. One asked, "Did this workshop change your perspective on making? If so, how?" Only a few students responded. They cited changes such as "I had no clue what it was 'till now", "it showed me that there is no limit to what you can make", and "I understood how to create more products". The first response came from a female student, the second from a black student, and the third from a white male student. I also gave them space to comment on the workshop, but no one did. Finally I included room for additional comments, which yielded a few responses. The only negative feedback was that the timespan was too short. Students listed a few things they liked, including the opportunity to learn new things and the opportunity to be creative and design their own lanterns.

Discussion

While the limited response rate of the survey prevented it from being useful for comparing the control and experimental workshops, it did provide useful information about middle school student perspectives on making. The fact that most students identified the purpose of making as a way to "learn new technical skills or concepts" affirms my hypothesis that students want more formal instruction in making, as many have a lot to learn. What is more, over half of the students disagreed with the statement that they could teach themselves new digital fabrication techniques before the workshop, suggesting that a laissez-faire approach to maker education would leave them lost and confused. At the same time, students highly rated purposes for making such as to "create customized products/gifts for myself or someone I care about" and "solve problems in my own life", suggesting that they already understand the value of making in their lives beyond school, an important part of Maker Empowerment. Knowing these types of personal relevance can help instructors address the differences in engagement levels in different groups of students.[1]

The student responses also hinted that they already realize the importance of seeking help. While most felt that they could not teach themselves new techniques before the workshop, most felt that they **could** figure out how to digitally fabricate most simple things they wanted either by themself or by asking people they know for help. I did not ask them to specify who they might ask for help in such a situation, so they could have anyone in mind, whether a friend, teacher, parent, or someone else entirely. Given that many considered digital fabrication something for "smart people or engineers" before the workshop, it is reasonable to assume that they had identified a "smart person" in their life as a potential helper. Students did feel that the term "engineer" described them somewhat, giving it an average of 3.2 on a 5-point scale, but it was not a dominant enough identity for many students to take the lead without help.

Students' excitement to learn was even more palpable in the workshops themselves. The students looked curiously at the vinyl cutter when they entered and crowded close to it during

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[1] While I was unable to measure socio-economic status in my research, it is important to consider its effects on motivation. Researchers in England found link between relevance and socio-economic status when studying the relevance of math to students at different schools. They divided student responses into "practical usefulness" or the direct application of math skills in work or life, "transferable process skills" or logical thinking skills that emerge through the study of math, and "professional exchange/entry value" which refers to the cultural prestige associated with math success (Sealey and Noyes 2010). They found that only students from more affluent communities recognized professional exchange value as a reason to study math, and the students from lower income families were likely to abandon math if they did not perceive it as useful in a hands-on, practical sense. In a maker context, this may translate as a need to emphasize practical applications of making such as fixing household items or saving money by building things rather than buying them. This is a different perspective than the "STE(A)M" emphasis in many schools, which often focuses on future high-paying jobs rather than present practical applications. However, more research should be conducted regarding the relationship between emphasis on "STE(A)M" and the relative motivation and success of students from lower socioeconomic backgrounds in making.

my demo. Some clearly had future project ideas in mind, asking whether the machine could cut certain materials. Wlodkowski proposes four practices to enhance student motivation, and suggests that each fall in a certain section of a class. One of the ones he recommends including towards the beginning is what he calls "developing attitude", or providing enough personal relevance and choice to promote a favorable attitude towards learning (Wlodkowski 1999, p. 12). All the students I directly encountered seemed to walk in with this favorable attitude fully developed. While I had prepared to make the somewhat intimidating concept of "digital fabrication" seem more accessible with examples of pop-up cards and screen printed shirts as potential projects, many students were already excited, and this step seemed to broaden their perspectives more than light a spark.

The other practice Wlodkowski suggests for the beginning of a class is to "establish inclusion" and create a learning environment of mutual respect and connection (1999, p. 13). In all four sections, students seemed comfortable asking for help and sharing their ideas with me and my co-teacher. Students were fairly active in asking for help when they were working with the actual software, most questions of the "How do I...?" variety. However, the two styles of workshops saw very different learning environments in terms of peer interactions. By asking students to pair up during the brainstorming phase and ask their partner questions about their design ideas, it seemed that I had established a classroom atmosphere of collaboration. Many students in those sections continued to ask each other questions and share their progress throughout the two hours, and some even stayed late with their partner as they cut their designs. In the other sections, students talked to one another much less, typically only if they knew one another from outside the class and primarily about off-topic issues.

While a productive social atmosphere does not guarantee that students remain motivated, it does assist with Wlodkowski's next two steps: "enhancing meaning" and "engendering competence" (1999, p. 13). Meaning is enhanced when students feel challenged in ways that account for their perspectives and values. Having a partner as a sounding board for ideas and a consistent source of feedback provides both a challenge and affirmation for students. In the brainstorming phase, students were encouraged to push their partners to answer a list of guiding questions and to explain their ideas through words, sketches, or paper models. Throughout the class, students then helped one another feel competent, voicing both praise for one another's success and validation for one another's struggles. The benefits of peer feedback have been touted by many educational theorists and even been incorporated in official education policy. The Department for Education in England encourages teachers to give students opportunities to share ideas with peers, suggesting that "by talking about the quality of their own work and the work of others children learn to evaluate" (Welch et al. 2000, p. 18).

Peer interactions have also been shown to alleviate student anxiety surrounding class participation. Panitz notes that "in a traditional classroom, when a teacher calls on a student, that student becomes the focus of attention of the entire class" (1999, p. 60). Rather than allowing a student's doubt or failure to become the object of group scrutiny, teachers can reduce the pressure by giving students a chance to work out answers and ideas with one or two peers before addressing the entire class. Teachers can also structure peer interactions and whole-class questions as more of a collaborative discussion than a test of understanding. Leach & Moon go so far as to advise teachers to ask questions of a whole class "if and only if they are about content that requires students to think deeply and discuss their own interpretations", suggesting that questions with a single correct answer have no place in direct instruction or class discussions (2008, p. 88). In a making context, this can manifest itself as questions such as "what is the difference between vector and raster files?", a question that should be answered through direct instruction anyhow and would only serve to isolate students without prior experience from students with more digital fabrication background.

While peer interactions are generally valuable, it is important that they are structured in a way that helps all students learn. Students from marginalized communities or who are new to a discipline may feel "detached from the learning communities they witness forming among their highly successful peers and teachers". It is vital that teachers demonstrate good learning practices and promote transparency in their curriculum, so no student feels left out of the class learning community (Leach & Moon 2008, pp. 69-70). An important type of good learning practices is positive group processes. Student groups, particularly when students vary significantly in ability, tend to be plagued by a practice called "social loafing", in which one or more students choose to avoid doing their share of work, whether because they rely on their more successful peers or they are retaliating against peers who expect them to do all of the work. When teachers encourage groups to use positive practices such as "positive interdependence, individual accountability, equal participation and good social skills", social loafing is found to play far less of a role, and students of all ability levels can benefit from the group experience (Wing-yi Cheng et al. 2008, p. 217).

Positive interdependence and individual accountability typically must be tailored to the specific project or task. Practices like "mutual learning goals (making sure all members learn the materials), joint rewards (each member will get bonus points if all members achieve a certain standard), shared resources (each member gets a part of all materials) and assigned roles" can be concrete ways to enforce interdependence and accountability (Wing-yi Cheng et al. 2008, p. 207). Another method, which I chose to use in my workshop, is it to require a separate output from each group member. Similar to assigned roles, this method offers students a clear individual focus. Even if the students chose to minimize the time they spent interacting with one another, each student would still emerge with a paper lantern of their own design and a better understanding of digital fabrication. Had I asked each pair to produce a single lantern, some students would likely have missed out on some or all of the design and fabrication process. While I struggled to force interaction during the brainstorming phase other than by asking questions of students about their partner's design, it was fairly easy to force interaction in later phase by using the concept of "shared resources". Partly spawned out of necessity as many students sought help simultaneously, I developed a practice of explaining a step to one student, and then asking them to teach their partner. This method of making students rely on one another for instruction seemed successful, as the student explaining the concept had a chance to solidify their knowledge and the partner seemed to grasp the concept as effectively as if I had explained it myself. It also highlighted gaps in understanding, as pairs would then call me or my co-teacher back over to ask a more specific question if they could not work through the task together.

It is difficult to know whether I successfully guided all of my students down a path towards Maker Empowerment, but I do believe I successfully addressed the three takeaways from the interviews during the workshop. My experience with the students during the brainstorming phase confirmed my theory that creativity can be scary for students. While none refused to design something altogether, many chose not to sketch or to erase their sketches after creating them, suggesting a lack of confidence engaging in creative activities. By giving students the option to talk through ideas with a teacher or peer as well as the option to modify images found online instead of just drawing, I believe I made more students feel comfortable generating ideas. Even the students who did not cut their full lantern by the end had some sort of design in the works that reflected their own interests or ideas. Giving students time to sketch on paper and discuss ideas before moving to the software also seemed to help the less technically-inclined students feel more confident. One student confidently sketched a design, but expressed his discomfort with the software once he started using the computer. Having the sketch completed first seemed to help focus him, as it made it easy for me to see what he wanted to accomplish and give him precise tips and it acted as a guide for him, giving him a clear starting point as well as a sense of completion when he fully replicated the design. While the practice of sketching before using software was not useful for every student, it was definitely valuable for some, and it is important to recognize students who can make incredible things but lack the technical background to do so immediately.

The concepts of role models and taking projects home also played an important role in the workshop. While I like to think that I and my co-teacher acted as role models to some extent, we were of course limited by our own backgrounds. As white, middle class MIT students, we of course could not seem relatable to the full range of students in the four sessions. However, we did our best to acknowledge our own difficulties when learning digital fabrication and the fact that we both had learned it much later in life and still progressed quite far, making it clear that these students were capable of even more progress by the time they reached our ages. The more important role models, I felt, were their peers. The students had a range of experience with art and a completely different range of experience with digital fabrication and computers in general, and they all seemed eager to see others' designs and get inspired. They also got a good deal of inspiration from their families, with some students citing their parent's making projects as inspiration, some making lanterns for their parents, and others excitedly showing their parents what they made as they left the class. By using cheap materials, I ensured that every student could bring their project home and even replicate it will materials at home, though they would most likely have to use scissors or an exacto knife to cut the shapes out.

Implications for Practice

1. ***Do not expect students to learn on their own, but help them develop the tools to do so.*** Many students do not believe that they can successfully teach themselves new skills, and expecting them to do so right off the bat can reinforce existing inequality in student preparation. The last thing you want in a makerspace is to prevent newcomers from being successful by only catering to students who already know how to figure out machines and software by themselves. Demonstrations, guided projects, and creating a culture where questions are encouraged help students develop the skills they need to get started. From there, teachers can introduce students to online resources and general approaches for making new things to help students move further on their own.

2. ***Choose activities that are accessible and interesting to students from a variety of backgrounds.*** Activities that are gendered, culture-specific, or too technical or artistic can alienate students who do not identify with the target audience. While many girls love building RC cars and plenty of boys enjoy fashion, it is important to be cognizant of traditional gender roles, particularly when targeting elementary or middle school students. Rather than choosing an activity that is typically targeted at a single demographic, try to select something neutral or more customizable to appeal to a wider audience. Providing options for students to use different colors, materials, and patterns also makes it easy for students to add a personal touch without much difficulty.

3. ***Recognize that making mixes artistic and technical skills, and provide support for students who currently lack either or both.*** I worked with a girl who erased every sketch she made and a boy who did not know how to undo something on a computer, and both required different types of support. Students have a wide range of backgrounds, particularly when it comes to non-academic skills, and those backgrounds do necessarily conform to stereotypes. Be prepared to provide validation and specific tips for less experienced students. Particularly if a student has neither an artistic background nor a technical one, it is important to highlight that both are learned traits, and that one is stuck being "bad at art" or "bad at computers". A growth mindset is vital to becoming a successful maker, so affirming student progress and sharing your own experience starting from their position can make a huge impact on students.

4. ***Encourage peer feedback, but not necessarily group work.*** Group work can provide valuable learning opportunities and teach students necessary life skills, but social loafing and peer comparison can have negative impacts if not recognized. One way to promote individual learning while still reaping some of the benefits of group work and creating a more vibrant class learning community is by using peer feedback during brainstorming and encouraging peers as resources throughout the whole process. Peers can teach one another skills they just learned, provide validation for others' successes, and empathize and encourage persistence when things go wrong.

5. ***Create opportunities for students to find role models and share their work with the role models they already have.*** Establish yourself as a resource and fellow learner who faced their own set of difficulties and opportunities to grow, but also do what you can to promote role models who are more relatable for students. Peers can play this role or you can bring in teaching assistants or guest speakers who share a similar background to your students. You can also harness existing role models by giving students projects that they can bring home and show to their families or better yet, giving students opportunities to work on making projects with their family so they can learn and create together.

Conclusion

Maker education is still in its infancy, and longer term studies and surveys must be completed before we truly understand the state of equity in making and best practices for promoting it. This study was limited by its size, relatively privileged context, and limited ability to collect quantifiable data. The students who choose to participate in Spark at MIT are hardly representative of students across the United States, as many live in and around the Boston area, a relatively wealthy and well-educated part of the country with access to high performing public schools and affordable after-school enrichment programs. The short time-frame of Spark also limited the amount and types of data I could collect. To truly understand the impacts of an introductory maker lesson, I would need to observe the students in subsequent maker scenarios over a longer timespan.

However, the workshops, survey, and interviews with maker educators did provide significant insight into the psychological barriers to making that many students in the Boston area face as well as teaching techniques for overcoming these barriers that are far more effective than just giving students unrestricted making time. The interviewees all emphasized the role of training projects to get students started and specifically recommended selecting projects that are relevant to students. Relevance has many facets, including relation to gender, race, and other identities that might bias students towards or against certain projects. Students also want to customize projects to their own tastes and will devote the most energy to processes and/or products that they can use in their life beyond the makerspace. Scaffolding is also vital to student success, as students are often anxious about their creative skills and/or their technical skills when approaching a new project. By offering specific feedback, clearly constrained tasks to get students started, and demonstrating the process for students right before they try it themselves, instructors can help students manage those initial fears and dive into a project.

But perhaps the most important part of starting students down a path of lifelong making is creating relationships. Students need mentors, ideally ones who share their background and have a similar identity, to inspire them to keep learning new skills and solving new problems. These mentors can be relatives or friends who support students through encouragement and feedback on their projects or they can be other makers or maker instructors who have already walked the path that students want to follow. Whether the maker instructor takes on this role depends on the situation and the student, but maker instructors should help promote these relationships by giving students materials that they can take home and share with existing mentors in their lives and introducing students to other makers with similar interests or backgrounds. Maker educators should also promote peer relationships as a way for students to learn and get feedback. By assigning partners for brainstorming and asking students to show one another how to do basic things, instructors begin to form a low-stakes community of collaboration, where students feel welcome to share their work or seek help but do not feel forced into group work or public presentations.

While these principles may not apply in every makerspace, I hope they can prompt maker educators to consider how relevance, scaffolding, and community influence the choices they make in their space. Not every student needs the same time of support, but all newcomers will need support of some kind, so educators need to be prepared to welcome and instruct students in a variety of ways. I hope that my fellow student makers and maker educators will continue to explore the nuances of how to create maker activities that are relevant, properly scaffolded, and capable of fostering community for all types of students. Together we can make space for all students in our makerspaces.

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Appendices

Appendix A: Lesson plan

Intro to Digital Fabrication with Paper Lanterns

Lesson Plan

Class length: 1 hour and 50 minutes
Class size: 0-8 students
Sections: 4
Materials: cardstock, tape, glue, LED tealights

Intended outcomes of this course for students:

To form a stronger identity with one or more of the following words and to realize that all of these types of people are valuable and capable of making great things: maker, hacker, tinkerer, inventor, engineer, crafter, artist, designer.

To see the value of making as a way to solve problems, express themselves, relax and unwind, learn new technical skills or concepts, and create products for themselves or others with more customizability and/or lower cost.

To want to learn more ways to make things using digital fabrication.

To gain confidence that they can teach themselves new techniques for digital fabrication and figure out how to digitally fabricate most simple things they want.

To realize that digital fabrication is for everyone and can be used to create a wide range of products.

Prep:

1. Print 32 copies of minors assent form, parent consent form, survey, further resources list, and guiding questions list
2. Get tape, glue sticks, cardstock, pencils, and scratch paper from Spark hq
3. Log in to computers, load software
4. Get vinyl cutter from MakerLodge

Introduction - 15 minutes

1. Welcome students, collect consent forms, have them fill out survey
2. Give brief overview of project
3. Explain vinyl cutter and where it fits into grand scheme of maker machines
4. Explain why we're using a vinyl cutter and what students will learn
5. Introduce examples of paper lanterns as inspiration

Ideation (control) - 15-20 minutes

1. Give students list of guiding questions, paper and pencils to sketch, paper to fold
2. Give them short amount of time to answer questions and prep ideas
3. As students appear to finish up, Jake/Kate will ask them to explain their idea and provide feedback

Ideation (Experimental) - 15-20 minutes

1. Have students pair up
2. Give student pairs each a list of guiding questions, paper and pencils to sketch, paper to fold
3. Give them short amount of time to discuss questions and prep ideas
4. Encourage them to bounce ideas of one another, give each other feedback
5. Kate/Jake will float and provide feedback on ideas as well as interactions

Demonstration - 5 minutes

1. Once all students are mostly done developing ideas, Kate will demonstrate full process of using software and vinyl cutter
   a. Design
   b. Cut
   c. Assemble

Designing and Cutting - 1 hour

1. Students will then have time to prepare their designs in the software
2. Jake and Kate will roam around and provide technical support as needed
3. As students finish, they will raise their hands to get Jake/Kate to check their design for cut-friendliness
4. As each student finishes their design, they will take a turn cutting their design on the vinyl cutter
5. While they wait for other students to finish, they can assemble their work and continue playing around with software or peruse list of further resources

Wrap-up - 10 minutes

1. Celebrate any successful cuts and provide supportive, growth-oriented feedback to students who were less successful.
2. Have students complete exit survey before leaving

Appendix B: Brainstorming worksheet

Brainstorm!

Here are some questions to get you started. Feel free to answer all of them, none of them, or something in between. The idea is to get your brain working on coming up with ideas.

1. Are you making this lantern for yourself or someone else?
2. What shapes do you/they like?
3. What symbols represent your/their identity or interests?
4. What sorts of things do you like to doodle?
5. What types of patterns do you/they have a lot of? Think about your clothing, bedsheets, throw pillows, bowls, posters, book covers, bags, etc. that have patterns or graphics on them
6. Do you want the light to primarily come out of one side of the lantern?
7. Where is the lantern going? Is there a specific room or piece of furniture it should match?

Use the space below to sketch and/or write things that come to mind:

Appendix C: Student survey

Pre-Survey

Please note: all questions on this questionnaire are optional and anonymous. If you feel uncomfortable answering any of the questions below, please leave it blank.

For the purposes of this survey, the phrase "digital fabrication" refers to 3D printing, laser cutting, vinyl cutting, and all other forms of CNC cutting.

To what extent do you feel the following words describe you (1: not at all, 5: very much)?

Maker	1	2	3	4	5
Hacker	1	2	3	4	5
Tinkerer	1	2	3	4	5
Inventor	1	2	3	4	5
Engineer	1	2	3	4	5
Crafter	1	2	3	4	5
Artist	1	2	3	4	5
Designer	1	2	3	4	5

Making things offers me a way to ___________ (circle up to three)

Solve problems in my own life
Solve problems in the world/other people's lives
Express my thoughts or feelings
Relax and unwind
Learn new technical skills or concepts
Create products I want at a lower cost
Create customized products/gifts for myself or someone I care about

Rate the following statements:

I want to learn more ways to make things using digital fabrication.

Strongly agree Agree Disagree Strongly disagree

I can teach myself new techniques for digital fabrication.

Strongly agree Agree Disagree Strongly disagree

I can figure out how to digitally fabricate most simple (small, non-electronic) things I want, either by myself or by asking someone I know for help.

Strongly agree Agree Disagree Strongly disagree

In a few words, describe the sorts of people you believe digital fabrication is intended for:

In a few words, describe the sorts of products you believe digital fabrication is intended to produce:

Pre-survey ends here. Please wait until the end of the workshop to turn the page!

Post- Survey

Note: many questions will be repeated from earlier. Please avoid copying previous answers and instead answer honestly based on your current thoughts

To what extent do you feel the following words describe you (1: not at all, 5: very much)?

Maker	1	2	3	4	5
Hacker	1	2	3	4	5
Tinkerer	1	2	3	4	5
Inventor	1	2	3	4	5
Engineer	1	2	3	4	5
Crafter	1	2	3	4	5
Artist	1	2	3	4	5
Designer	1	2	3	4	5

Making things offers me a way to ___________ (circle up to three)

Solve problems in my own life
Solve problems in the world/other people's lives
Express my thoughts or feelings
Relax and unwind
Learn new technical skills or concepts
Create products I want at a lower cost
Create customized products/gifts for myself or someone I care about

Rate the following statements:

I want to learn more ways to make things using digital fabrication.

Strongly agree   Agree   Disagree   Strongly disagree

I can teach myself new techniques for digital fabrication.

Strongly agree   Agree   Disagree   Strongly disagree

I can figure out how to digitally fabricate most simple (small, non-electronic) things I want, either by myself or by asking someone I know for help.

Strongly agree Agree Disagree Strongly disagree

In a few words, describe the sorts of people you believe digital fabrication is intended for:

In a few words, describe the sorts of products you believe digital fabrication is intended to produce:

Did this workshop change your perspective on making? If so, how?

What specifically did you like/not like about the workshop? (list as many things as you want)

Anything else you want to share about the workshop, your views on making, or your maker identity?

How would you describe your gender?

Female Male Other: ____________

Which do you feel best describes your racial identity?

American Indian or Alaska Native

Black or African American

Asian

White

Other: ______________

Do you identify as Hispanic/Latinx? (circle one)

Yes No

This is the end of the survey. Thanks for participating!

Appendix D: Additional Resources List

Bonus Maker Resources!

Maker Tutorials and Project Ideas

Remember to always use safe making practices and get adult supervision when working with power tools, sharp objects, or electricity. Some of these sites contain examples of projects that are too dangerous to do without expensive safety equipment, so please use caution and consult a parent before trying things at home. That being said, I encourage you to explore, ask questions, and dream big about what you can make!

instructables.com - a one-stop shop for instructions on nearly anything you'd want to make
Makezine.com - curated articles on maker projects, including some you can do at home
learn.sparkfun.com - lots of detailed tutorials on electronics, from beginner projects to complex ones
Learn.adafruit.com - more electronics tutorials, plus cool project ideas
makerspaces.com/makerspace-projects/ - tutorials geared towards schools and libraries, so a good source for cheap and easy projects to get you started
www.youtube.com/beautyandthebolt - video tutorials covering the basics of different making skills
highlowtech.org/?cat=20 - cool electronics projects developed by a former Media Lab professor

Boston-area Youth Makerspaces

These spaces all have some sort of free walk-in hours (or walk-in hours included with museum admission). I encourage you to share this list with your parents and friends and take a field trip to visit these spaces. They all have trained instructors to help you make cool things safely, and most have technology like vinyl cutters, 3D printers, and laser cutters that you probably don't have at home.

BPL Teen Central http://www.bpl.org/teens/at-the-bpl/teen-room-central/ - Copley Square, Boston
Fab Lab Boston aka South End Tech Center https://www.facebook.com/pg/FabLabBoston/about/?ref=page_internal - South End, Boston
Hatch http://www.watertownlib.org/hatch - Watertown

Parts and Crafts https://www.partsandcrafts.org/makerspace/open-shop/ - Somerville
MIT Museum Idea Hub https://mitmuseum.mit.edu/program/idea-hub - Cambridge
The Flagship Clubhouse @ The Museum of Science http://clubhousebeat.org/ - Science Park, Boston