# From Making to Micro-Manufacture: Catalyzing STEM Participation in Rural High Schools

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## ABSTRACT
This paper proposes *Micro-Manufacture* (M2), a model of Making that extends its practice to include aspects of engineering concerns of production and reproducibility. A longitudinal study was conducted with six high school students engaging in the M2 model within the scope of a two-year long Career and Technical Education class. We investigated the potential of M2 to convey educational benefits and to affect Making and Engineering self-concepts. Quantitative results showed that the students generally made positive gains in Making and Engineering self-efficacy, but that the real-world requirements of M2 caused Maker mindset perceptions to be more negative. Qualitative findings however showed that M2 requirements served to focus the students, and enabled them to develop skills that they may not have otherwise developed by simply engaging in conventional Making activities.

## Author Keywords
STEM, Making, Manufacturing, Self-efficacy, Apprenticeship

## ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION
Making is generally identified as having some specific recognizable characteristics. First, Making is usually seen as a hobbyist rather than a professional practice. Second, Making typically entails experimentation processes such as tinkering, iteration and prototyping. And third, Making is mostly geared towards the creation of single (unique) artifacts. This paper proposes a model of Making that extends its practice beyond the typical characteristics to include aspects of engineering concerned with production and reproducibility. The model that we call, *Micro-Manufacture (M2)*, addresses small scales of production (essentially the Making of one to Making of many) for real-world concerns.



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We argue that M2 has further educational potential for students. Much literature has documented the impact of Making in improving both STEM learning outcomes [1, 2] and the acquisition of the Maker mindset, defined as a particular frame of mind whereby individuals believe that they can make things to solve problems [3]. We conducted a longitudinal study with six high school students in a rural public school to explore the potential of M2 to convey educational benefits and to affect Making and Engineering self-concepts.

In our study, students were exposed to 'Making' (e.g., basic electronics, 3D fabrication, and basic programming) and 'production/industrial engineering' (e.g., process engineering, project planning, quality assurance, inventory management, and industrial distribution) through a practice-based approach. The micro-manufacture context was designed to serve a pragmatic need within the students' community: the learning material needs for a local science elementary school classroom. Given the relatively small number of students in an elementary school classroom (approximately 20), small scale production is warranted.

We believe that M2 has further educational potential for at least two key reasons. First, by broadening the practice of Making to the real-world need for small volumes of reproducible artifacts, we help students to transcend the often-circumscribed world of 'canned Making'. Jenkins and Bogost explicate this through their sandbox metaphor [4]. Play sand is meaningful only within the sandbox – were the sand to spill over onto the lawn it just becomes unsightly contaminants to be swept away. Likewise, materials and practices of Making often make sense within the context of the Makerspace, but is often irrelevant in the real-world.

Second, the requirement to produce in real quantities for the real needs within one's own community provides greater motivation for Makers to engage in processes and behaviors that will serve their continued aspirations in both work and higher education: for instance, important life skills that include teamwork, leadership, critical thinking, problem solving, and time management. At the high school level at which our study was conducted, M2, in its combination of Making, production engineering and life skills, matches the closest with usual educational standards for ‘Career and Technical Education (CTE)’ (e.g., [5]).

In the rest of the paper, we provide an overview of relevant literature that connects the practice of ‘Making’ with ‘STEM’ education alongside ‘Engineering’ and ‘Production Management’ concerns. From there, we will describe our M2 model in greater depth. Afterwards, we overview the context and methodology of our study. Following that, we describe both quantitative and qualitative results from our study. We conclude by discussing the findings of our study with respect to how the M2 model can chart a new pathway for research in Making.

## RELEVANT BACKGROUND

The ‘Maker Movement’ is motivated by innovations in technology, the outsourcing of technologies, and the accessibility of programming. The movement represents the collective of hobbyists and professionals working together to create their own functional products regardless if they are technological devices, open source libraries, fashion apparel, home decorating, or any everyday device [6]. The outcomes of the movement have been that technology artifacts can now be created by a wider audience at a greater frequency and a higher level of sophistication.

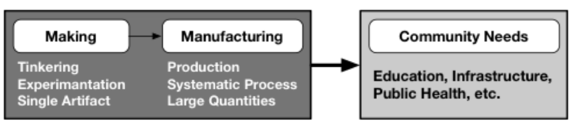


**Figure 3. Micro-manufacture model**

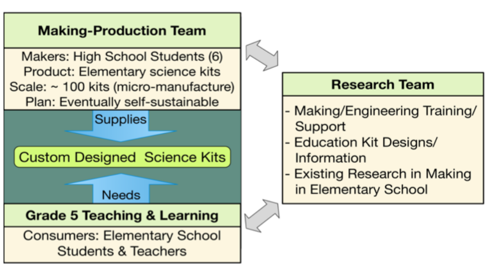


**Figure 4. Case study scenario of micro-manufacture**

There are a wide range of definitions of what is Making as well as ongoing debate as to what technologies and practices that this comprises. In their review of existing definitions of making, Martin defined Making as activities focused on the design, building, modifying, and repurposing of materials for playful or useful ends; this through the use of either hobby techniques and digital technologies [7]. Honey and Kanter focus their definition with an emphasis on personal fabrication through the act of building or adapting objects by hand [8]. Sheridan offers that making is the creative production in areas in art, science, and engineering where digital and physical technologies are used to explore ideas, learn skills, and create new artifacts [9]. Kuznetov and Paulos identifies making as a subset of DIY practices that involves creation, modification or repair of objects through one’s own capabilities [10]. While there are divergent views on what Making consists of, our perspective of Making in this paper is that it involves the construction of artifacts through the combined use of three main sets of technologies: basic electronics, 3D fabrication equipment, and computer programming.

We emphasize two key aspects of Making of relevance to our work in this paper. First, is the hands-on nature of Making. Blikstein notes how the physical practices that comes with Making and digital fabrication can help to materialize the design and engineering concepts inherent within it [11]. Making is a hands-on process based on how individuals engage and experiment with materials, similar to Donald Schön’s ‘conversation with materials’ [12].

Second, Making represents more than the specific sets of equipment and methodologies used, where it is conducted, or the community in which it takes place. Making is at the center of a culture that is centered on the valuation of personal production and problem solving. This culture possesses what is called a ‘Maker Mindset’ which refers to a particular frame of mind that encourages individuals to believe that possess the means to solve problems faced [3]. It has been effectively argued that possession of such a mindset can ultimately lead to learning outcomes relevant to STEM domains [13].

The ‘Maker Mindset’ is an outcome of the concepts of self-concept and self-efficacy. Shavelson et al. describe self-concept as one’s self perception with respect to how one understands how they act and anticipate their future actions [14]. One’s self concept changes as individuals engage and experience the environment (e.g., outcome interactions with peers or materials). Self-concept contains both cognitive and affective facets towards the self [15]. The cognitive facet involves awareness and understanding of one’s self and related attributes. The affective facet is based on one’s own sense of self worth that comes from one’s own approval or disapproval at any given time [16]. Self-efficacy differs to self-concept where the former refers to how individuals cognitively assess their own capability to perform an action, situated as a subcomponent of self-concept [15, 17]. Self-efficacy, as defined by Bandura, refers to “the conviction that one can successfully execute the behavior required to produce the outcomes” [18]. These two concepts are relevant in how we can observe how the Maker Mindset can influence one’s own appraisal of their skills in STEM and possible involvement in it.

## A MODEL OF MICRO-MANUFACTURE

The typical definition of Making in the literature is that of a hobbyist practice, akin to an arts and craft activity that focuses on the hobbyist-like tinkering of computationally- and electronics-based parts. For instance, Halverson and Sheridan [13] defines the Maker movement as “the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others”. We propose a radically different conceptualization of Making that augments Making with production or manufacture at small scales. This model, which we call micro-manufacture, is illustrated in Figure 1. Since Making has been shown to impact students' sense of self-efficacy in STEM domains, we were interested to investigate whether micro-manufacture may have the same effects on self-concept. Our research questions were as follows: RQ-I: *How do students engage in M2 as an educational experience?* RQ-II: *Does engagement in M2 affect students' Making and Engineering self-concepts?"*

## METHODOLOGY

### Study Context

Our study was conducted in collaboration with a school district located in a remote rural community along the Texas-Mexico border. Rural communities along the border tend to be small, economically distressed, and under resourced communities, which often times result in their underrepresentation in STEM fields. Six high school students were recruited to be part of the study, which took the form of a technology class. Recruitment were done by circulating an application form through the teachers among all the sophomore and junior students. Students were recruited on the basis of having a diverse mix of students in terms of interests and capabilities. Our study was exploratory in nature, we wanted to observe differences within the study across types. A total of 13 applications were received. The 13 applicants were interviewed through teleconferencing, and a total of six students were selected. The selection of the students was done such that the six students represented a diversity of interests, backgrounds and career goals.

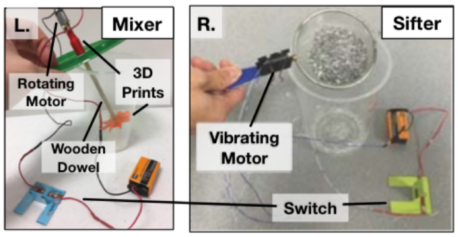


**Figure 3. Science kit for the 'Mixtures & Solutions' elementary curriculum topic**

In our case study scenario, shown in Figure 2, the community need that we set was to provide a Grade 5 elementary school science class with instructional kits to support their science learning. The elementary school was located in the same school district as the high school, such that the needs being satisfied through micro-manufacture were situated locally.

Skills and instruction in micro-manufacture (Making skills such as soldering, basic electronics, 3D printing, etc. and manufacturing skills such as supply chain, inventory management, batch processing, production line, etc.) were taught to the high school students through a distance apprenticeship approach by the research team that consisted of members with knowledge in Making, computer science and engineering, industrial distribution, educational technology and interaction design.

### Science Instructional Kits

The science instructional kits, that acted as the Making targets of the high school student participants, were aligned with specific elementary science topic learning standards taken from the state-mandated curriculum. The elementary school class consisted of 15 students. Science kits were to be used in pairs, with some components sometimes prone to minor breakages, so the high school students needed to produce at least 10 kits for each science topic.

All designs and details about the kits were developed by the research team, and then delivered to the high school students. The kits were designed to be usable by children as young as 8 years old, and so combined arts and craft with basic electronics. For example, the 'Mixtures & Solutions' kit (Figure 3) aimed to teach elementary school students how mixtures are created (e.g., how gravel and sand mix). The kit demonstrated this concept using different materials (e.g., gravel, sand, metal clips). The kit comprised of two children-constructed components, an electronic mixer and an electronic sifter. The electronic mixer was made of a geared rotating motor that controlled a 3D printed mixer head. The mixer head was held together by a 0.25" dowel rod. The electronic sifter used a vibrating motor attached to a conventional sifter. The circuitry of the motors for both components was set up through a paper-based switch and connectors linked to a 9V battery.

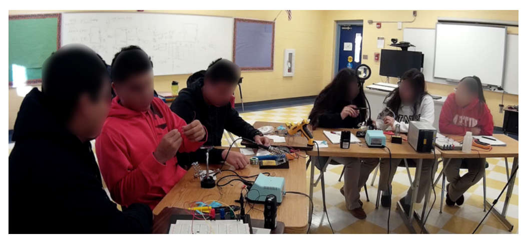

**Figure 4 High school students in classroom makerspace**

### Study Description

The high school technology class that functioned as our study context lasted for a period of two years. Year one served as an introductory training for Making and M2 for the high school students, and Year two involved the high schoolers manufacturing and deploying their kits in the elementary school classroom.

*Year I:*

'Year I' served the purpose of teaching the high school students the skills necessary to develop and produce the instructional science kits. The project started in the second semester of Year 1, and thus our study in Year 1 covered 18 weeks. The team of six high school students were taught Making and manufacturing skills (Figure 4). A makerspace was set up in a classroom in the high school with the following small equipment such as soldering irons, hand tools, initial inventory for basic electrical wiring, and a 3D printer. Students were charged with independently organizing the workspace to support the Making and manufacturing of the instructional kits.

Training was given in two stages. First, the six students attended a face-to-face 1-week workshop at the researcher team's site. Subsequently, the high school students, working as a Making-Production Team (MPT), practiced making and manufacturing sample kits in sufficient quantity during their daily technology class for the rest of Year 1. The class was conducted each school day via teleconferencing by an undergraduate or graduate student from the research team. Each class started with a recap of previous class instruction and a review of the current production of kits. Following, instruction was given on the topic of the day. Finally, students engaged in the actual micro-manufacture activities that were scheduled for that day.

The micro-manufacture process was explained to the students as consisting of: i) understanding and decomposing given kit design and specifications; ii) adapting kit design to local conditions; iii) Making of one kit; iv) planning manufacturing; v) engaging in a production pipeline; vi) quality testing; vii) deploying kits in the classroom; and viii) conducting a post-mortem assessment of the deployed kits. The students engaged in the practice production of 6 science kits that varied in terms of materials used throughout Year 1.

*Year II:*
The second year for the MPT followed a similar process as year one, but the concerns of satisfying the elementary school science classroom were real. We present data up till the end of the first semester of Year 2, and so Year 2 consists of 18 weeks in this paper. The high school class followed a six-week schedule for the production and deployment of one kit because the elementary school schedule was such that one science topic was covered every six weeks. Moreover, the roles of the high school students in the MPT were more formalized in Year 2. For each science kit, each member of the MPT took on one of six roles: 'Project Manager' (PM), 'Production Manager', 'Sourcing Manager', 'Administrator', 'Continuous Improvement Specialist', and 'External Relations Manager'. The roles were developed based on the logic of a system at equilibrium. Systems possess input, processing, and output attributes. These attributes can be seen as we have a role dedicated to input (e.g., Sourcing manager on purchasing), processing (e.g., Production manager on pipeline process), and output (e.g., External relations). Delivery and deployment of the science kits for a topic was done by the high school students traveling to the elementary school on the day of the science lesson, and helping the 5th grade students to use the kits during the assigned period.

### Measures

At the beginning of Year 1, the high school student participants filled in a pre-study questionnaire. Subsequently throughout Year 1, at the end of every week, the students were asked to complete an end-of-week survey. In Year 2, the students were asked to fill in the survey at the end of each six-week cycle (i.e., end of deployment of a science kit). We note that students sometimes missed filling out the weekly surveys, and so these weeks are considered as missing data in our analysis.

The survey measured the following using 7-point Likert scales: i) **'Maker Mindset'** using the Maker Mindset Assessment [19]. The assessment is made up of 11 items and measures different aspects that have been described as characteristic of a Maker in the literature, for instance, creativity, social responsibility, teamwork, etc. Example items are "I am willing to help other people", "I like to share things I make with other people"; ii) **Making and Engineering Self-efficacy** using adapted versions of the 'Sources of Self Efficacy' scale [20]. Example items include "I feel I am very good at engineering" and "Being good at engineering is an important part of who I am".

The weekly questionnaire asked open-ended questions on how the student perceived the week's activities, and what they would like to make with the skills/knowledge they gained that week, and why. A single Likert scale also asked them to evaluate how much they think they are able to actually make what they described as their desired personal project.

## DATA ANALYSIS AND FINDINGS

### Data Analysis

All the items in the Maker Mindset scale were averaged to give a single composite score for each student. That score thus represents the degree that a student self-reports as possessing the characteristics of a Maker at the point of measurement. For self-efficacy, since the measures were scales, all items were averaged to have a score for Making self-efficacy and Engineering self-efficacy for each student each week of measurement.

Each student's response to the weekly questionnaire with respect to "what they would like to make" was coded in accordance to the type of object they wanted to make for a given week. For example, participant S1 wanted to make more long circuits, so it would be coded as a 'Science Kit' object. Another example can be seen where S5 wanted to make a replacement button for a game controller; this object would be coded as a 'Personal' object. Participant's responses on their ability to make the state product was coded descriptively. For example, Participant S6 believed they could make a robot because they know where to find the information to do so.

Open-ended items on the questionnaire were analyzed using a qualitative coding method based on grounded theory to derive themes. We used a two-stage approach. 'Open Coding' was used first to generate initial descriptive categories. and 'Axial coding' was used to refine themes [21].

We engaged in a form of narrative inquiry to formulate case studies. Narrative inquiry seeks to understand the complexity of the lived experience of participants through "collaboration between researcher and participants, over time, in a place or series of places, and in social interaction with milieus" [22]. Understanding gained from narrative inquiry enables the researcher to discern where the participants came from, and ascertain the participants' possible futures. Data from conversations, online and offline chats, interviews, and questionnaires was integrated from the purview of the story that they tell about the participants.

### Findings

The findings are first reported below by research question, followed by two case studies to provide the reader with a better understanding of the experience of the students engaging in M2.

#### *RQ-I: Student Outcomes through M2 Educational Experience*

M2 requires that students acquire domain-specific as well as integrative knowledge and skills across Making, manufacturing, and general work-life. The students showed that they gained sufficient knowledge in each of the three aspects of M2, and were able to successfully integrate the domains to make the science kits. We describe below 4 themes that we saw in terms of knowledge acquisition from M2:

**i) Increasing proficiency in basic skills through manufacturing:** Students had to repeatedly practice Making skills through a manufacturing process to accomplish their goals. When the project first started, students would act more individually and build components on their own. While this process works well for small numbers of objects, when they started making many items that process needed to be adapted. Students started breaking down tasks into individual strengths, and would often form an assembly-line for more complex components. For example, one of the first components they had to make was a paper switch. Making these switches require printing paper, laminating paper, cutting paper, attaching copper tape, and soldering on wires with soldered and heat-shrunk connectors. When they first learned about that these switches, it took a while to make them start to finish as each student had to walk through every step while sharing resources. To overcome this, students applied Gantt charts to break down the process into small steps and plan a more efficient making-process by parallelizing several steps among themselves. These steps were often then completed by students who felt they could complete those particular tasks efficiently and accurately. By the end of this study, this led to individual students acquiring specialties in certain tasks. For example, one student became the team's 3D printing expert, and a subset of the team would readily solder items. Once a plan was in place, students would often complete tasks in parallel with little talking, reusing Making skills to manufacture components.

**ii) Manufacturing skills are harder to acquire than Making skills:** While students often would complete independent Making tasks without much reminder, planning and organization tasks necessary for manufacturing often were often ignored unless an instructor helped walk them through it. We hypothesize that students lacked motivation to complete these tasks because of the lack of immediate tangible validation for these tasks. When 3D printing, cutting paper, soldering, and other Making tasks, students were able to immediately see their progression towards a project. With planning and organization tasks, the product of their labor was not directly related their goal of classroom deliverables. Instead these manufacturing skills result in streamlining of tasks and organization of people and materials, resulting in an efficiency that is less tangible to those inexperienced in manufacturing. Near the end of the study, the students had picked up some habitual manufacturing skills such as workspace organization and separation of duties. For example, when researchers asked students how many parts they had ready, at least one student could readily say what parts had been assembled and what was still incomplete. However, manufacturing tasks like creating a shopping list of parts to order and writing down a gantt chart in a formal matter still did not occur without intervention near the end of the study. These skills may become more ingrained into habit given more time, but that cannot be said in the scope of this study.

**iii) Life skills are what makes M2 work:** Students developed and exhibited skills not exclusive to Making or manufacturing, life skills like leadership, teamwork, problem solving, and time management. Near the end of the project, students were able to craft solutions to certain problems without researcher intervention. For example, when constructing a mixer (Figure 3) that normally utilized a motor to spin a wooden dowel attached to a 3D-printed fan, the students discovered they did not have wooden dowels readily available. To wait for dowels to ship would have delayed their deployment and cost them more money, so they took initiative and arrived at the resourceful and thrifty idea of reusing items in the classroom. Instead of the wooden dowel, the students utilized standard wooden pencils that had similar-enough dimensions to work with the rest of the mixer.

Students did have familiarity with each other at the start, but that transferred into a working familiarity. This allowed them to communicate more effectively immediately. They knew each other's' names, interests, and overtime they learned their respective Making and manufacturing abilities. As the students rotated their leadership responsibilities, the leaders knew how to assign tasks because of this implicit knowledge of each other, facilitating better teamwork. Through this study, students gained valuable, tacit life skills related to working within a team and taking initiatives.

**iv) Application to personal life scenarios:** Students learned by abstracting general concepts from class lessons towards similar projects in the program or their own maker projects they would like to engage in (e.g., After initial lesson on LEDs, S1 wanted to implement LEDs in a phone charger). When students faced projects they would like to pursue but can't engage immediately, they noted that they can make up for this apparent gap in knowledge by being aware of resources that could inform them or reliance on more capable others (e.g., S5 wanted to).

*RQ-II: Self-Efficacy*

We were interested in the extent to which engagement in M2 would affect students' perception of themselves as Makers and as engineers. The data points seen in figures 5 through 7 represent the averages of all 6 students survey responses of a given week. The data points seen represent the total available data points collected from the students. Of note, the students did not always complete the weekly

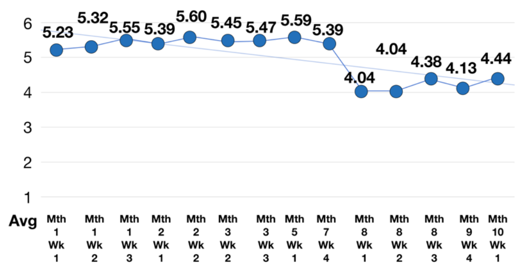


**Figure 5. Weekly 'Maker Mindset' Averaged Weekly Scores**

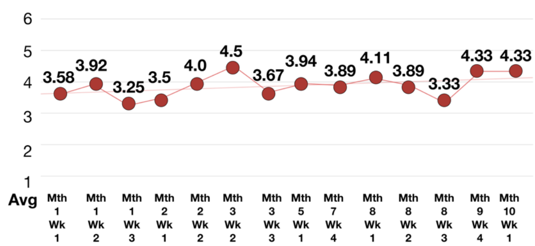


**Figure 6. Weekly Making Self Efficacy Scores**

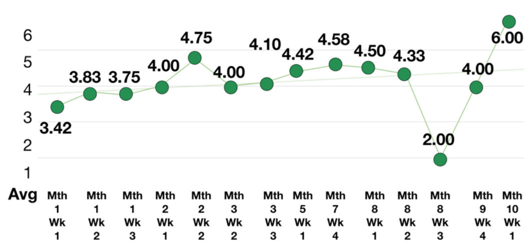


**Figure 7. Weekly Engineering Self Efficacy Scores**

surveys, thus resulting in jumps between weeks.

**i) Maker Mindset:** Figure 5 shows the students' average (across all 6 students) self-reported scores on the Maker Mindset measure by week. While the scores are generally high across all weeks ($M$ = 5.10 overall), there is a clear trend whereby the students increased in Maker mindset in Year 1, and experienced a sharp decrease in Year 2.

**ii) Making Self-Efficacy**: Figure 6 shows the average Making Self-Efficacy scores over the two years. Accounting for usual variations of measures over time due to the idiosyncrasies of the specific kits each week, class experiences, life events, etc., Making Self-Efficacy generally showed a weak positive trendline from the beginning of Year 1 to end of Year 2.

**iii) Engineering Self-Efficacy:** Average scores from the engineering self-efficacy scale, shown in Figure 7, indicates a slow increase from the start of Year 1 to almost the end of Year 2. The last few weeks of Year 2 showed a sharp increase after a drop. However, we determined that the drop was caused by events external to the M2 program.

**iv) Micro-manufacture beyond the classroom**: Having the imagination of being able to make personal things using the new M2-related skills that the students acquired is another indication of whether the students perceived themselves as Makers. From their open-ended questionnaire responses, students wanted to make artifacts that we classified in two categories: i) artifacts that related directly to the science kits that they were making for the elementary school (e.g., "create more sophisticated prints", "produce more mixture solutions projects"); and ii) artifacts that were of personal use (e.g., portable cell-phone charger, replacement button for game controller, Christmas lights, fidget spinner). Counts based on the two different types of artifacts (Figure 8) show that the number of science kits-related artifacts increased over time, while the number of personal artifacts decreased.

The students' average scores of how much they believe they are able to make the artifacts they listed as possible outside projects showed a negative slope over time (Figure 9). That is, they were less confident of being able to make their listed artifacts as the study progressed.

*Case Studies*

The two case studies below were chosen from the set of six student participants because they illustrate some of the richness of the students' growth as Makers during their engagement in M2 within their technology class. Names used in the narrative are fictional to preserve participants' anonymity.

The students as a group began the study with some experiences in hands-on work owing to their upbringing in a rural environment. Experiences came from involvement in for instance, ranch work (e.g., Stephen has previously worked with his Dad on maintaining a truck's electrical wiring), or repairing domestic products (e.g., Roger worked with his uncle to take apart a phone to repair it).

***i) Maria – 'From Business to Education as Career Pathway':*** Maria already considered herself to be somewhat of a Maker at the beginning of Year 1 of our study. She brought up her experiences in repairing things at home (e.g., "Because I like to make things. Especially with my little brother; he had like an airplane thing, but the wings broke off, so I tried fixing it and fixing it and I just kept trying until I finally got it."). Her understanding of Making, however, was limited to it being about math and the production of mechanical objects.

When asked about her career interests, Mary indicated that she wanted to go to business school to perhaps become a real-estate manager. It was evident that her choice of career was dictated by the fact that she strongly believed that she was "very good" at Math. In fact, her one attraction point to what she fashioned as engineering was that it involved the application of Math in the designing of products.

As a side interest, Maria also has a love for children and had taken up babysitting as one of her outside-of-school activities to gain some pocket money. Maria applied for the M2 program because she believed she could learn how to make everyday objects for use (e.g., making a replacement button for her brother's game controller). But when accepted into the program, she was especially excited that she would be able to interact with younger elementary school children.

Throughout the program, despite being one of the two more senior students on the team, Maria tended to be a follower more than a leader. Her quiet personality was such that she would turn to others for ideas or directions. But over time, Maria became a critical part of the team in the sense that she transformed from a follower to a mediator. The production needs of M2 often created great stress on the team dynamics because of the scope of the Making, quality of products required, and delivery deadlines. Lucy, who has more of a perfectionist stance, often argued extensively with Rita, who had more of a *laissez-faire* attitude. For example, Lucy were sometimes adamant on some of her ideas for the kit prototype, for how work should be distributed, or for the acceptable quality of manufacture of the components. Maria became the broker between Lucy and Rita to ensure that the M2 team kept up with production concerns.

Maria was not one who engaged in the innovative aspects of Making. She was not forthcoming with the prototyping, tinkering with materials, or problem-solving with the 3D printer as some of the others were. Instead she was engaged in M2 at the level of production. For example, with the basic skills of soldering, crimping and heat-shrinking that she learned, she always took charge of making the wires connections for paper switches. Her interest in Math also led her to consistently take charge of doing the inventory plan so much so that she became eventually the only one on the team who fulfilled that task.

At the end of Year 1 of the M2 program, Maria decided to apply for college. She was accepted as a business major at a university. But towards the end of the program, Maria suddenly requested for a switch of major from business to education. When asked about it, she related she would now like to become a science teacher.

***ii) – 'Roger: Finding a Path Towards Higher Learning':*** Roger considered himself a maker at the start of Year 1 of our study, motivated by his experience repairing things around his home with his Uncle. Before the study, he had experience with tasks like disassembling and reassembling phones and various electronics to functional order. Roger was unsure if he could learn engineering on his own at the beginning of the study. Remembering that his Uncle taught himself to fix things, he was motivated to learn more about engineering through the M2 program.

Building on his experience with electronics, Roger's proclaimed favorite and best subjects are technology and math. Roger wishes to utilize these skills in the future to become a software programmer in the future. In Roger's spare time, he enjoys learning about different aspects of computers ranging from building one to learning how to write his own computer programs. He's expressed that he would like to move his interest towards robotics, this in terms of actually building the robot and actually programming the hardware that controls it. At the beginning of the study Roger believed engineering to be "mostly technology and math", and associated Making with engineering because of "the circuitry and technology" that went into it. Roger applied for the M2 program because he believed he will learn what engineering is, and how its applied in the design and production of technology.

Roger acted on his interest towards the hardware and software aspects of computing. In terms of hardware, Roger alongside another student took on the role of 3D printing technician as the class progressed, troubleshooting any issue that arose when printing out parts such as when the printer head failed to extrude. With respect to software, Roger experimented with programming through the Arduino. One example of Roger's software interest can be found when during the workshop session. Roger was among the few students who was successful in programming and wiring an Arduino to blink RGB LEDs in his custom science kit project. This task was not required of Roger, but he completed it so he could learn more about controlling hardware with software.

Currently, Roger has one more year in his high school education. Since his involvement in the program, Roger has stated that he feels confident in his ability to enter into a undergraduate engineering program in computer science.

## DISCUSSION

Micro-manufacture goes beyond Making by bringing in aspects of manufacturing at a small scale. This expanded model of Making creates the need for the Maker to now attend to concerns and situations that are much closer to real-life. In our study, our six high school student participants engaged in micro-manufacturing to satisfy the needs of a local elementary school class for instructional science kits.

Our findings allowed us to better understand the kind of educational experience that M2 creates for students. At a general level, the inherent need for repeatability in M2 due to the small-scale production needs ensures that skills are acquired and even perfected. Subsets of knowledge and skills associated more directly with manufacturing rather than Making appear to be more challenging for the high school students to grasp and to be motivated to engage with. It seems that intangible life skills such as teamwork and responsibility are critical aspects of a functional M2 ecosystem. And students in M2 are to a certain extent able to imagine the application of their skills to more personal projects.

At a more specific level, M2 provides the opportunity for some who may otherwise not have engaged in Making to still be involved, for instance, Maria engaging mainly in production aspects in terms of hands-on skills and planning processes. M2 impact students more than just in terms of

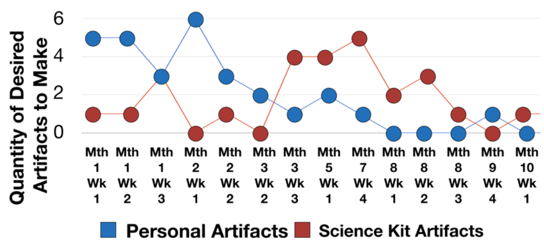


**Figure 8. Weekly Counts of Participants Desired Artifacts to Make**

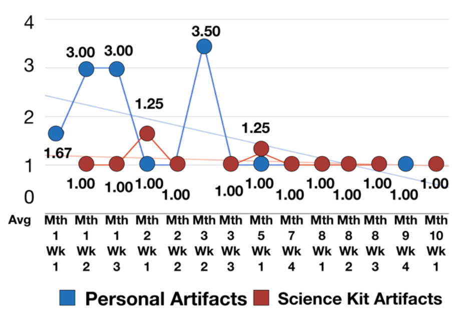


**Figure 9. Students' Average Scores on Self-Efficacy to Make Artifacts**

STEM. While specific to the type of community problem that we set up in our study context (elementary instructional science kits) for the students, we saw how engaging in fulfilling those community needs had perhaps as great or greater impact on the students, with the most explicit evidence of that being the case of Maria changing to an education instead of a business degree.

Overall, M2 appears to engage students in educational experiences that are distinct from that of conventional Making activities. Our quantitative results reinforced this as well. M2 requirements such as the need for actual delivery and fulfilling for real clients seemed to affect the students' Maker mindset self-evaluation. Mindset scores remained high in Year 1 when the program was in the training phase and no real delivery occurred, but as soon as the program transitioned to real-life client fulfilment in Year 2, mindset scores showed a drop. This drop can perhaps be attributed to the students' shift in experience from contained practice to actual practice with expectations and deadlines to work within. It would be interesting to see whether, as the program continue, Maker mindset scores recover. On another note, the M2 requirements of production and delivery seem to cause the students to focus. They improved on many fronts from Making skills to life skills, and even in their lists of desired artifacts to make, we saw the students placing an increasing emphasis on wanting to do better on the kits (products to be delivered) over artifacts for their own personal use.

It is also worth noting that the decrease in Maker mindset scores in Year 2 stands in contrast to the positive slope of Making self-efficacy. Thus, M2 requirements of actual delivery in Year 2 did not seem to have affected how proficient the students felt like they were in Making. Skills expertise consistently increased, even while self-concept was impacted.

## CONCLUSION

In this paper, we investigated the extension of Making with its emphasis on exploration and construction of singular artifacts with an infusion of the engineering needs to reproducibility and production. Our study suggests that this extension results in an alteration in the students' practice and perception of the activity and technology. In a sense, the processes of Making and manufacturing become real, and able to address real need to which the manufactured artifacts are applied (elementary school learning in our case). The students show strong signs of the development of a community of practice with recognition of each other's skills and preferences. It illustrates how the students 'become' Makers and manufacturers with self-identified roles and recognition of these roles by their peers (much in a way an apprentice midwife takes on the role of a midwife and is recognized as such by the community [23].The pragmatic need of producing on time for a real purpose also fostered the development of the less tangible life skills of leadership, teamwork, responsibility, time management, and problem solving.

The study was limited with respect to the specific setting and number of participants used for the current study. Another weakness is the timescale between surveys. Early on the study the frequency of surveys were more consistent but as the program progressed, the periods were more sparse. As our research program continues, we plan to further study the strengths of the M2 approach, specifically focusing on the learning and self-concept outcomes in prolonged involvement in M2. We will want to examine how the M2 approach would scale with respect to the existing community and size of participant populations.

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