# Motivating STEM Participation through a 'Making as Micro-manufacture (M3)' Model

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# Motivating STEM Participation through a “Making as Micro-Manufacture (M3)” Model


## Abstract

The objective of this paper is to outline a new model for motivating STEM participation and developing self-efficacy among high-schoolers, and to detail the major implementation activities involved, preliminary impressions/results, and lessons learned.

In this model titled, “Making as Micro-Manufacture (M3),” high-variability low-volume products were manufactured in real-world settings and for a real-life purpose. The model combined “Making” with engineering concerns attendant to manufacturing at micro scales (tens to hundreds of parts) along with domain knowledge (elementary school science). Practice-based learning was implemented, in which a cohort of high school students from an underserved border community in Texas worked as an autonomous Making-Production Team (MPT) to produce instructional hands-on science kits for their own community’s elementary school. By working in a scenario simulating professional practice, the MPT members pragmatically integrated Making activities with aspects of production scheduling, inventory, and supply-chain management. The eventual goal of this activity was for the MPT members to learn engineering concepts and develop a STEM self-concept that only such thick practice could provide.

Supported via distance mentoring and summer training workshops by a Texas A&M University‘s engineering technology undergraduates, the approach was tested in a rural underserved border community with populations typically underrepresented in STEM. Evaluation mechanisms consisted of questionnaires, interviews and video recordings of work sessions. Altogether, the preliminary results and lessons learned helped shed light on aspects of implementation critical to the successful full-scale deployment of such self-sustainable MPT teams, both in developing themselves, as well as in serving and growing within their own close-knit community.



## Keywords

STEM, Making, Manufacturing, Self-efficacy, Apprenticeship.


## Introduction

The U.S. has traditionally led in technology innovation with respect to manufacturing. However, this edge has waned as other counties have been able to compete with the US with respect to consumer-product development and manufacturing. This can be seen in countries that can produce the same products at higher quality and lower cost. In order for the U.S. to remain competitive at a global scale, it is necessary to change how engineering education is organized with respect to the knowledge and skills in manufacturing technology and efficiency.

Rural communities have borne the brunt of this with the US lagging in manufacturing competitiveness. Our model, we believe, will be of benefit to rural communities. Our program, "Making as Micro-Manufacture (M3)" proposes the following:

1) Give students the knowledge and familiarity to integrate electronic tools with scientific domain knowledge,
2) Create an immersive learning experience through the integration of 3D printing, electronic prototyping, and crafting in the classroom,
3) Gain the tools and techniques that support business operations and customer requirements in an efficient manner, and
4) The formation of a STEM self-concept that promotes career preparedness for either future college or career success.

This approach was piloted from our National Science Foundation (NSF) Early-Concept Grants for Exploratory Research (EAGER) project titled, "Making in The Colonias: Motivating STEM Participation through a Making as Micro-Manufacturing Model" [1, 2]. In short, the program introduces high school students to basic technical skills in Making (e.g. basic electronics, 3D modeling and printing, and computer programming) and basic industrial engineering concerns (e.g., industrial distribution, materials acquisition, process planning, and quality assurance). It is believed that high school students involved in this distance apprenticeship program will develop career and college-preparation skills.

In this paper, we pose the following research question concerning our M3 model: "How may the M3 model be actualized in a low resource community?". We aim to illustrate the following. First, we want to outline our model for motivating STEM participation, this being our 'Making-through-Micro Manufacturing'(M3) model. We believe that through participation in our model, students will develop self-efficacy in STEM fields as well as interest in pursuing STEM education and careers. Second, we aim to detail the evaluation of our model in the form of a two year high school engineering program. From this we will highlight our approach, preliminary results, and lessons learned.

## M3 Model

Making can be understood in one of two ways. First, making as a practice refers to the tangible objects ranging from sketches to the fully manufactured objects [3]. Second, it can refer to a new paradigm of hacking as formation of creative communities with alternative lifestyles rooted in emergent technologies and innovation" [4]. Finally, it can refer to a collective of individuals who "as a "growing community of hobbyists and professionals dedicated to making their own functional devices, whether it be technological gadgets, open source hardware and software, fashion apparel, home decorating, or nearly any other aspect of physical life" [5].

Altogether, making is beyond equipment used, certain methodology, a specific place, or a community. We argue that making is a culture that values personal production and problem solving. This is evidenced by the maker mindset [6] which refers to frame of thinking that one has or means to solve any problem faced. We believe that possessing such a mindset could lead to learning in STEM domains.

While the potential for making could help lead to learning in STEM domains, existing approaches to making in school settings frustrate this possibility. Kits such as Lego Mindstorms or LittleBits [7] are characterized by consisting of pre-fabricated materials that involves some level of assembly on the student's part. The problem with kits such as these is they make it difficult to understand how skills acquired in the activity can be translated to other parts of the student's own life. Essentially, it minimized the benefit that making has been suggested to have in education. This issue can be understood through Jenkins and Bogost [8] metaphor as existing approaches to making in school as akin to playing in a sandbox. While the student may engage in making as an activity within the "sandbox", these same activities when placed outside of their artificial context ceases to be relevant to other areas in the student's life.

Making is currently approached as a form of 'boutique manufacturing' in that it revolves around the production of a single, personalized, end-product. 'Boutique manufacturing' doesn't require consideration to repetition or reproducibility of a product [4]. Our approach, 'Making through Micro Manufacturing' (M3) builds upon existing practices in making, but considers how existing technologies and approaches can be coupled with manufacturing at micro scales. Unlike traditional manufacturing where products are produced in high volumes, M3 approaches production at the scales of tens to hundreds. In addition, the products produced through M3 are built to address a real-life purpose.

Essentially, if the act of making was placed within a context that has real world demands and deadlines, the STEM elements that are inherent in making can be made all the more obvious. This could be attributed to one of three ways. First, it situates making in contexts that are personal, culturally, socially relevant to students. Second, it can encourage students to be part of a production pipeline and contribute to something novel and useful to society. Third, involvement in this form of making places students in long-term scenarios acting as Makers fully engaging in STEM. We believe this approach to making can enable students to gain a holistic view of their making ability as well understand how developed knowledge can be transferred. This reflects Grotevant's process of identity formation as arising out of continual exploration and evaluation [9].

## Evaluating the M3 Model

To evaluate the M3 Model, M3 was put into practice in the form of a two year program with high school students acting as a 'Making Production Team' (MPT) team to produce instructional hands-on science kits for their community's own elementary school.

What is notable about our evaluation of our model is as follows. The project concerns how to engage high school students in STEM education and careers. The high school students are characterized by being under-represented within STEM, under-resourced in their schools, and are coming from economically distressed communities. The Colonia community of Bruni is one such group. The Colonia community is situated in the southern border of Texas. The community is characterized by its "sense of family" within the rural setting. First is the sense of pride from community as high school students aid in helping local elementary school students. Second can be seen in the buy-in from the local community as the school supports their communities and families.

***Learning in M3 model consists of two methodologies:***

The first element is apprenticeship. We used apprenticeship as the process for training high school students in STEM domains of knowledge. We base our approach on Lave and Wenger's theory on situated learning [10]. Situated learning suggests that learning occurs in processes where they are peripherally involved. The idea is that students gradually learn the language, principles, and tasks associated with an enterprise, in this case in producing instructional making kits. This form of immersive learning is accomplished through students' engagement in a low-risk simple activities**)**

The second element is practice-based learning (PrBL) in real world tasks. After the high school students acquire the skills required in making, students then fully engage in PrBL processes. This is performed as students work in 'messy scenarios' where they take inventory in what is known, not known, generate possible solutions, formalize existing issues that can be addressed through self-directed learning [11, 12]. Students engage in PrBL as they use their established Making knowledge and skills to adapt existing instructional materials with respect to available supplies, expectations on the part of elementary school teachers, and a set deadline for deployment of kits in the classroom. The ultimate goal for this activity was for high school students to gain familiarity with engineering concepts, to develop self-concept with STEM fields, and to encourage lifelong interest in STEM.

## Details of the M3 Model in the Colonias

Here we will describe the overall timeline of the M3 program for the first year as well as a portion of the second year activities.

***Year I:***

When starting the project, we initially made contact with Webb CISD through an existing contact through our department's ongoing relations with the Colonias community. Webb CISD can be characterized by its its situation in a rural setting, serving a homogenous population of Hispanic students. Initial contact with the school district was primarily through phone and email. The purpose of the initial contact was to understand the constraints of the school, gain input from the administration on our interests, and finally, identifying a class that could act as a vehicle for investigating our M3 model in supporting high-school STEM education. From here, we identified teachers that were interested in supporting STEM interest in high school students and developed a working relationship. Two members of the research team went to Bruni high school to personally meet with the administrators and teachers. The overall goal was to get a sense of the community's status. The community was considered underserved where resources necessary for STEM education weren't always available and out of its way with respect to urban/semi-urban centers.

Following from the development process for the Maker kits in the 'Making-the-Maker' project [13], we provided a framework for the kind of knowledge that was necessary for the high school students to develop the instruction kits for the elementary school children within the same school district. We identified the needed skills in four categories. First we had Making skills such as basic soldering, wire connections, 3D printing and design, circuits, and fabrication. Second, involves concerns around production in areas such as bulk production, supply chains, and inventory management. Third revolves around the translation of elementary science domain knowledge into designed kits. Finally, we had design and ergonomic structure. When these skills were identified, they were formalized and catalogued. Figure-1 below shows one of the high-schoolers in the process of assembling a paper switch as part of an instructional kit for teaching elementary school science concepts to their community's 3-5 graders.

*Figure 1 - A High-Schooler from MPT Assembling a Paper Switch for use within an Elementary School Science Instruction Kit*

After the curriculum was formalized with respect to materials (i.e. illustrative slides, videos, and references), we next developed the protocols for instruction in our apprenticeship-based practice. Given the distance between our university and the Colonias community, we opted to use teleconferencing by way of the Skype platform. We organized class structure in accordance to daily and weekly timelines. A daily class would start with a recap of completed and in progress activities while reviewing the big-picture context of a current kit design. Afterwards, there are a few minutes of instruction for the topic of that day. Finally, the students engage in hands-on tasks for the remainder of the class. Weekly class structure was organized with respect to the current step in the production pipeline ranging from initial setup of a requested kit, understanding the decomposition of its parts for production, ordering of parts needed, prototyping existing or modified designs, planning manufacturing, engaging in manufacturing, deploying the kits, and finally, performing a post-mortem review of strengths and weaknesses of the deployed kit design in the school. In addition, we also included weekly self-reporting to measure student's self-efficacy in the domains of making and engineering as well as overall feedback to the M3 program itself.

A data collection and transfer framework was established at the end of year I. An online google drive account was setup. The account itself was used for the purpose of sorting and transferring of project related data and documents. This includes information pertaining to curriculum materials, tentative schedules, updates on current progress, daily recorded data (video and audio), high school student submissions, graded reports, and prototype design files. An additional google drive account was established, this serving the purpose of organizing collected data from the weekly surveys the high school students completed. The TAMU faculty team had access to this google drive account.

We put out an open call for students in our program within the Bruni high school through the support of their teachers. We restricted participation in our program to students who had at least two years left in their school work (i.e., sophomore and junior classes). The high school teachers particularly encouraged students who they personally felt would be good for fit for the program and would stand to benefit from it. Students engaged in our call for participation through an application. The application form asked students for information such as their background, experience, career plans, and overall goals. We received a total of 13 applications. We down selected these 13 candidates through 10 minute Skype interviews with the students, asking students to elaborate more on their academic interests and career trajectory. Following their responses, the faculty team independently ranked the students and through discussion came up with the final selection. We opted for a 6 students in an effort to keep the gender ratio balanced. We also balanced for class level and broad general interest of the student. After selection, we sent our formal invitations to all 6 students. All selected students accepted participation in our program.

Two members of the faculty team returned to the Colonias community to personally meet the selected students. During this visit, the two PIs went to the students' high school and provided the initial setup and arrangement of the Making/Production workspace. The following were included in the workspace's setup: small equipment such as soldering irons and hand tools, initial inventory of supplies for basic electrical wiring. As students engaged the space over the course of a few weeks, students were charged with the responsibility of reorganizing the space with respect to the efficient manufacture of the instructional kits at the scale of ten to hundreds.

Training of the high school students commenced at a hosted workshop at Texas A&M University of March 2017. The six students and two teachers were brought to Texas A&M University to engage in a 1 week in-person workshop. The purpose of the workshop was to provide instruction on the set of knowledge and skills required to make the instructional kits. The students were taught skills with respect to design and 3D printing, besides being exposed to a university environment (Figure-2).


*Figure 2 - High-Schoolers from the Colonias Region during the 1-week Training Workshop at Texas A&M University*

Students in the M3 program engaged in a drill that simulates the practice of developing instructional kits for elementary school students for year 2. The students met daily during class. While these classes were in session, either an undergraduate or graduate student affiliated with the faculty team conducted class as a mentor through Skype. The mentor acted as both a consultant and teacher.  Students were supplied existing instructional kit designs from the 'Making-the-Maker' project and tasked with engaging in the production pipeline, as if they were to be deployed in an actual classroom. The classroom teacher will act as the Colonias manager, charged with capturing video and audio recordings of in-class progress. In addition, they will also collect and send digital copies of the documents generated during class.

***Year II:***

The second year for the MPT follows a similar procedure for Making and Production, differing where real world concerns are taken into consideration. These concerns include the pressures of actual practice and working towards an end-product that satisfies the demand of elementary school teachers. For the academic year, the MPT will prepare 6 different instructional kits, each one addressing a particular science domain previously established by the Oilton elementary school teacher. The kits themselves are deployed every 6 weeks, with a total of 3 kits deployed per academic semester. On the days that the instructional kits are deployed, the MPT will observe usage in-class with respect to elementary school children. After deployment, the elementary school teachers are asked to complete a questionnaire that assesses the quality of the instructional kits. The questionnaire is an adaption of the IBM usability questionnaire [14]. For our study, we use the questionnaire themselves as a means of determining the effectiveness of the MPT training following our M3 model. A snapshot of the MPT is given in Figure-3.

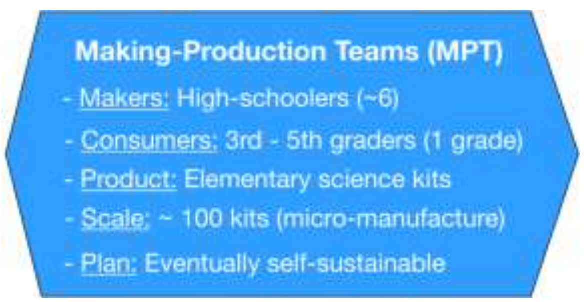


*Figure 3 - A Snapshot pf the Making-Production Teams (MPT)*

**Actors in M3 in the Colonias**

The M3 model as was set in the Colonias community can be understood in terms of three groups of actors. First, we have the elementary school teachers who provide the demand for customized instructional science kits and delineate the domain knowledge that the kits should embody. Second, we have the high school students who go through a production pipeline from concept, design, engineering, manufacturing, and finally deployment of kits. Finally, we have the University Support Team who provided the initial training, supplies, and ongoing off-site support and consultation as instructional science kits were in production.

The elementary school teachers provided the initial expectations for the instructional science kits and timeline for delivery to the high school students. The high school students are told the specific domain knowledge that the instructional kits should represent. Essentially the high school students are charged with translating domain knowledge to the core design of the instructional science kits. The relationship between the elementary school as an organization and the high school students can be characterized as symbiotic. Its symbiotic in that learning takes place with respect to the elementary school students  through the kits and also for the high school students as the real-world demand, expectation, and timeline teaches them design, engineering, and production management.

The high school students worked collectively as a group to produce the instructional science kits. For each unit, the high school students work in a six week production pipeline. While working in this timeline, the student take on one of six roles: 'Project Manager' (PM), 'Production Manager' (ProdM), 'Sourcing Manager' (SM), 'Administrator', 'Continuous Improvement Specialist' (CIS), and 'External Relations Manager' (ERM). Students are not fixed in these roles for the whole of our program, nor are they fixed in their activities from day-to-day production. Instead, the roles serve the purpose of distributing responsibility across the high school student team. The students took on different roles each individual six-week production timeline for the instructional science kits.

The ‘University Support Team’ (UST) rely on two resources in supporting the high school MPT. First, the ‘UST’ uses prior experience and knowledge gained from the ‘Making-the-Maker’ NSF funded project [1, 2]. Second, the ‘UST’ works with Texas A&M University’s ‘Engineering Technology & Industrial Distribution’ (ETID) department for the broad knowledge that is necessary to address the application of micro-manufacturing with respect to Making practices. The ‘UST’ has supported the high school MPT in two ways. The UST first provided knowledge support by training workshops. MPTs are first trained in the program by attending a 4-week summer instruction and training work at Texas A&M University. During that time, students work in a team consisting of 2 ETID undergraduate students, a graduate student, and faculty advisors. The teams collectively work in a vertically-integrated fashion. After training, MPTs proceed on to the academic semester where they develop instructional kits for the Oilton elementary school. At this time, the university team will then serve a support role either through on-site visits, through teleconference alongside Webb CISD personnel, and coordinating with the Oilton elementary school teacher on kit development and deployment. The UST also supported the high school MPTs monetary wise. Monetary support was provided to MPTs in the form of a two year stipend. This element served to both minimize the access barrier for the students but also to contribute to their families’ own economic welfare. The above outlined actors in the project, their roles, and interactions are outlined in Figure-4. ‘E’ and ‘F’ refer to the proposed M3 approach, and making-based curricula/projects, respectively.

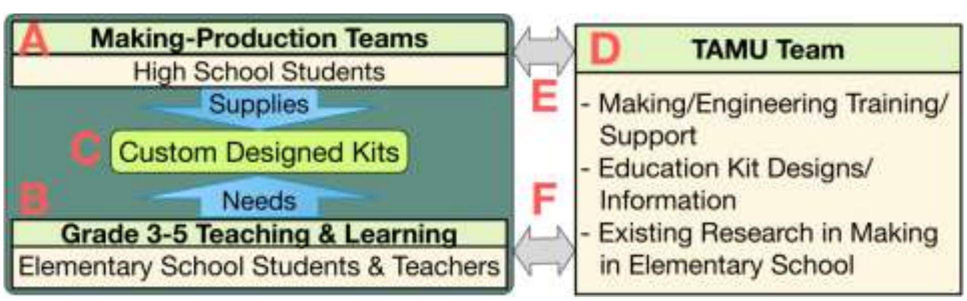


*Figure 4 - General Project Plan, the Participants, their Roles, and Interactions*

## Preliminary Findings

The M3 program as of now is still in progress for the life of the two year project. Here, we will describe some preliminary findings on the part of the high school students involved in the project. The data was collected through three sets of measurements, these including the high school students' project diaries, produced documents, interviews with teachers and mentors, and weekly audio and video for each day of production. Given that the research was an exploratory long-term study of 6 students, the data generated was too small to use for any meaningful statistical test. Through our weekly surveys, students have reported increases in self-efficacy in both making (*"I think I can make it because I know how to use the 3D printer"*) (Figure-5) and engineering (*"I think I can make it because the circuit we are learning to do right now is similar to a flashlight"*) (Figure-6). The making 'self-efficacy' scale was adapted from the 'Sources of Self Efficacy' scale as was previously used in [15]. Some scale items include, "I feel I am very good at Making" and "Being good at Making is an important part of who I am". The responses were rated on how true or false each statement was for them on a scale from 1 (definitely false) to 6 (definitely true).

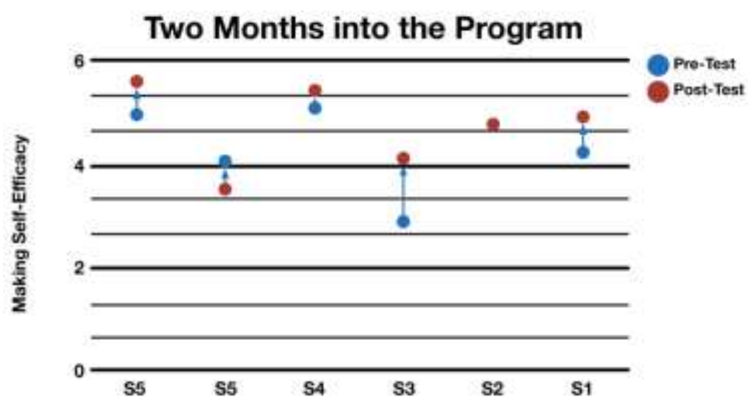


*Figure 5 - Making Self-Efficacy Scores in first Two Months of Program*


*Figure 6 - Averaged Engineering Self-Efficacy Scores in first Month of Program*

## Conclusions

The purpose of this paper is two-fold. First, we sought out to outline our M3 model as a vehicle for motivating STEM participation and self-efficacy in high school students. Second, we wanted to detail our initial evaluation of our M3 model in the form of a two year high school engineering program.

We first described our M3 model as the coupling of 'Making' as a practice alongside with engineering concerns such as manufacturing and production scheduling. Our M3 model has implications for manufacturing in the near future as well as how we educate our students for the new workforce. We evaluated our M3 model through a two-year "practice-based" distance-learning program, situated in the "Colonias" community. What is notable about the "Colonias" is that it is an exemplar of an economically distressed community that holds a population that has traditionally been under-represented in STEM fields. Communities such as these could consequently benefit in exposure to STEM through our model. Our initial findings suggest that students in our program developed consistent increases in self-efficacy in both the practice of making and engineering.

We argued that our M3 program is simple in its implementation as it ties the production of low volume and customized instructional kits for elementary schools to high schools within the very same community. Our approach is symbiotic where there are education outcomes for both the elementary school students through the learning kits and for the high school students through the need to design and produce the kits under real-world demands and deadlines. Finally, our program is sustainable as there is buy-in from the surrounding community, owing to the 'sense-of-family' in the rural community.

Future work for our research program will further evaluate the practice based learning model with respect to training students in M3. This research was done with a more homogeneous population as is characteristic of rural schools. Future research should address how the approach functions in more diverse urbanized populations. In addition, we seek to better understand how engagement in M3 can influence STEM knowledge acquisition and self-concept in participating students.

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