Developing Communities of Practice through Peer Mentorship in Making through Micro-manufacturing Model

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Abstract

The purpose of this paper is to focus on how the "Making as Micro-Manufacture (M^2)" model, can elucidate STEM learning and self-efficacy outcomes in high-school students through the development of communities of practice in the classroom. We focus on a dual-tiered curriculum for motivating STEM participation and self-efficacy in high school students. Here, we will detail how a dual-class curriculum was designed, established, and implemented alongside STEM learning and self-efficacy outcomes for students.

The M^2 model focuses on how high-variability, low volume-products may be produced in real-world settings and for the real-life purpose. We use the M^2 model as a motivating scenario in the form of practice-based learning course where high-school students produce instructional, hands-on science kits for a partnered elementary school of the same community. The program has two cohorts of students in the classroom, one of which has prior experience in engaging in the M^2 model and its application in the production pipeline for instructional science kits. In our second year of the program, we investigated how these two cohorts interacted with each other in the classroom. 'Junior' members, who are of the incoming class, are provided a survey of knowledge and skills necessary to engage in the M^2 model. 'Senior' members, who previously participated in the program one year prior, are charged with a focus on the managerial aspects of the production, delegating process-oriented roles,' and acting as peer-mentors for 'Juniors'.

Participants of the program were supported via a combined team of distance mentoring, training workshops by a Tier I University's engineering technology graduate students and professors, and on-site high school and elementary school teachers. The participating population are situated in a rural, underserved border community consisting of populations typically underrepresented in STEM. The evaluation was performed through the joint use of questionnaires, interviews, and video recordings of daily class sessions. Collectively, our results demonstrate how a community of practice is developed among the two-class cohorts, holding implications for the potential for STEM learning and self-efficacy outcomes as students are given personal charge of classroom outcomes.

Keywords

STEM, Making, Manufacturing, Self-efficacy, Community-of-Practice.

I. Introduction

Traditionally, the U.S. has been a contender in technology innovation, especially in manufacturing. However, this edge in manufacturing has waned as other countries have grown competitive in their consumer-product development and manufacturing. Given this current state, in order for the U.S. to be a viable competitor at the global scale, it is necessary to change how manufacturing engineering education is structured with respect to knowledge, skills, and efficiency [1, 2].

Looking towards Making and its implications on production and education could address these issues and return US to manufacturing advantage. Making is generally understood by three core characteristics. First Making is typically viewed as a hobbyist practice rather than a professional one [3]. Second, Making brings with it experimentation through tinkering, iterative development, and prototyping [4]. Finally, Making is geared towards the creation of single unique artifacts [5]. Making holds the potential for a significant educational impact for students. Prior work has documented how Making can improve both STEM learning outcome, this through the acquisition of a Maker mindset. The Maker mindset refers to the particular frame of mind where individual believe they can make things to solve problems. Making is beyond the equipment used, methodology employed, context of engagement, or community it takes place in. Instead, we argue that Making is a culture that values above all, production and problem solving. This sentiment is reflected by the idea of the maker mindset, which refers to the frame of mind in which individuals believe they possess the means and capability to overcome any problem they may face [6]. Possession of such a mindset could prove fruitful for learning in STEM associated domains.

While Making has the potential for STEM learning and self-identity outcomes for students, current approaches to how Making is situated in the classroom challenge these outcomes [7]. First, Making as applied in the classroom is removed from any real world context. Making in the classroom is often in the form of a kit such as Lego Mindstorms or Little Bits [8]. Such kits are characterized by a collection of pre-fabricated materials that call on assembly on the students' part. The issue that stems from this approach is that while the student may develop some mastery over this specific form of Making, students are unable to understand how developed mastery may be translated outside of the classroom (e.g., A student has prior experience in creating a blinking LED circuit through the Little Bits kit, but are unable to replicate the same functionality when working directly with a circuit board with respect to wiring, soldering, and troubleshooting subcomponents). Essentially, it minimizes the benefit that Making could have on education. Jenkins and Bogost have described this issue as the sandbox metaphor, where play sand is meaningful within the sandbox, the moment it spills into the lawn it becomes unsightly and ultimately swept away [9]. Similarly, the materials and practices that are associated with these existing kits fail to be relevant when situated in real world contexts of settings. Second, the products of making are typically approached as a form of boutique manufacturing, meaning that created products are single and highly personalized. Such products employ production skills that doesn't consider the repetition or reproducibility of a product.

Our model, 'Making through Micro Manufacturing'(M^2) couples existing practices in making with considerations of manufacturing at the micro scale [7, 10]. Products built through M^2 are produced in low volumes and address real-life purpose end-use. We applied M^2 to our study through a high-school level technology education course that exposes students to Making production technologies and production/industrial engineering considerations. M^2 through this course was situated as a scenario driven by real-world demands and expectations, this through the partnership with a nearby elementary school classroom. Students in the high school program were charged to produce instructional science kits as the products they produce in the M^2 program.

Previous findings included the following. Students reported increases in self-efficacy in making and engineering [10]. First, the M^2 model suggests that students gained both domain specific and integrative knowledge skills across Making, manufacturing, and work-life areas. Second, engagement in M^2 affected students' perception of themselves in being able to participate in making and see a future in which they could follow into engineering education and careers [7]. Finally, students' engagement in M^2 resulted in active engagement as indicated instances of self-instruction, demonstration, role assumption, and asking questions across peers, mentors, and teachers.

In the third year of our program, we investigated how student's STEM learning outcomes and self efficacy have implications towards the development of community of practice. Here we focus on a dual-tiered curriculum for motivating STEM participation and self-efficacy in high school students. Here, we will detail how a dual-class curriculum was designed, established, and implemented alongside STEM learning and self-efficacy outcomes for students.

In section II, 'M^2 Model in Review', we will overview the details of the M^2 model. In section III, 'M^2 and Community of Practice', we will detail how the M^2 can be used to facilitate a community of practice. Section IV, illustrates our implementation of M^2 with our partnered high school. Following after, section V, 'Findings', overviews our current findings.

II. M^2 Model in Review:

'Making through Micro Manufacturing' (M^2) is based upon existing practices in making but differs where it extends it by considering how its practice may be coupled with manufacturing considerations at micro scales and customer service (on-demand fulfillment). Traditionally, manufactured products are produced in high volumes, at the scales of thousands. In M^2, production is considered at the tens and hundreds. Products that are typically made at this scale are typically specific to a context, often serving to address a real-life purpose (Figure 1).

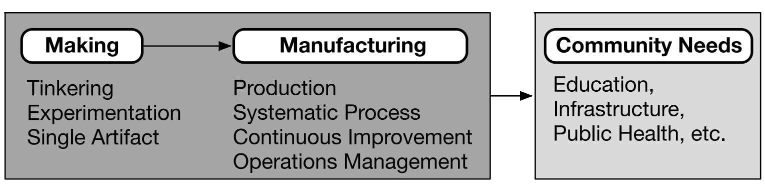

Figure 1 M^2 Production Model

Where M^2 goes beyond traditional making is its relationship to real-world contextualization. M^2 places making in situations where there are real world demands and deadlines. These contextual elements could make STEM elements more obvious. This could be in one of three ways. First, the M^2 approach places making in a context that is culturally and socially situated to the students' own experience. Second, it exposes students to the facets of the production pipeline, leading them to the potential to develop novel and useful products for society. Third, M^2 creates a scenario that places students in long-term production as Makers fully engaging in STEM. Altogether, this approach could give students a holistic view as to their developed making skills may be transferred. This reflects Grovetants' identity formation specifically as to how the M^2 holds implications on teamwork, leadership, critical thinking, problem solving, and time management [11].

III. M^2 and Community of Practice:

Our approach in designing the CTE course as a semi-autonomous entity was driven through the joint use of three frameworks. Each of these frameworks to be presented each indicate how mentor relationships can occur among experienced and novice students in the class.

For our approach for the third year, we employed the theoretical lens of Lave and Wengers' 'Situated Learning' (SL) and 'Communities of Practice' (CoP) [12]. The framework enables us to best understand how students learn M^2 processes but also how their involvement could suggest how they could take on leadership roles in the future[13]. These two theoretical frameworks places emphasis on knowledge acquisition but also the formation of the practitioner. CoP examines how individuals of a community establish and share understandings of a practice[14]. Such a community is motivated to the advancement of the practice and social capital of the group and not necessarily the product associated with the practice [15]. Such actions take in the form of live interactions surrounding practice or recalling stories related to practice [16]. CoP includes the following components. CoP is developed through Mutual Engagement (negotiation on how a practice is performed), Joint Enterprise (the end goal of the practice), and a Shared Repertoire (the shared resources of the group) [16]. Strong CoPs are characterized by the high frequency of knowledge exchange among peers, this leading to the reliance on one another for knowledge rather than referencing paper or online sources [17]. For CoP to arise in this fashion, the participants of this group need to establish mutual trust through experience in common relevant practice [18].

We employed Vygotsky's social development theory on the zone of proximal development (ZPD) [19-21]. The theory emphasizes that learning takes place through the transmission of knowledge through social constructs present within a community. Individuals possess a ZPD which refers to the level of knowledge that a student can attain when working with the help of a more knowledgeable other (MKO) [22].

The Makerspace Learning Practice (MLP) framework identifies the set of practices that may arise within a Makerspace [23]. These indicators include 'Learning Practices of Inquiry' (How is exploration and discovery motivated by curiosity?), Tinker (e.g., purposeful play, testing, risk-taking, and evaluation of materials, tools, and processes), 'Seek and Share Resources' (How do individuals identify and pursue the sharing of expertise with others), 'Hack & Repurpose' (How are materials, tools, and processes to modified to enhanced or created for new product or process), 'Express Intention' (How is personal identification discovered, evolved, and refined in relation to involvement?), 'Develop Fluency' (How does involvement lead to development of comfort and competence in tools, materials, and processes), and 'Simplify to Complexify' (How understanding is demonstrated through active reconfiguration of components for new meaning).

CoP enables us to understand how M^2 processes take place and how students can potentially become leaders in associated processes. ZPD enables us to examine how students roles arise in the dynamic learning exchanges among students. Finally, the indicators of learning practices can enable us to assess whether there is unstructured learning and how it facilitated in the classroom.

These three frameworks inform our study as depicted in figure 2. CoP is established in the interpersonal interactions and relationships among the Junior and Senior class. MLP serves as a lens to highlight activity outcomes present in specific maker activities within the class. In the example case of 'Tinker', the junior student gains the knowledge and skills to tinker in Making though the guidance of the Senior student, with the former leveraging the Junior's existing tangential familiarity with Making to bridge the gap to new skill levels.

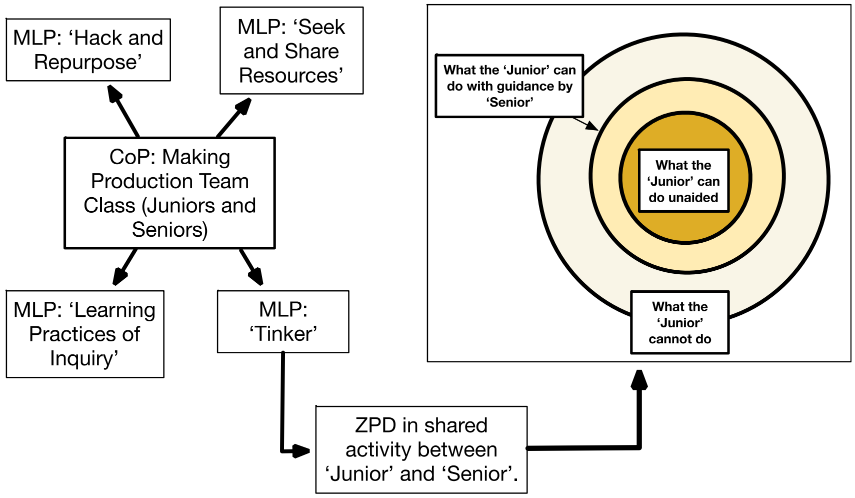

Figure 2 Framework for Classroom CoP in M^2

IV. Details of M^2 with Community of Practice:

Design:

The study was conducted as a collaboration with a school district situated along the Texas-Mexico border. The community can be characterized as rural, economically distressed, and under resourced with respect to tools and opportunities to engage in STEM fields. The program was developed to bridge this apparent gap. In its first two years, six high school students were recruited out an initial subject pool of 13 students. Students were selected on the basis of diversity of interests, backgrounds, and career goals. Students were interviewed through teleconferencing, with a total of six chosen. For the third year, two of the original team graduated, two were unable to participate due to scheduling. There was an open call for additional students for the class, with a total of two more students. The new students had no experience with the program as the other two participants in the current class year.

For our study, science instructional kits served as Making targets for the high school student participants. The studied high school, partnered with a local elementary school science class, tasked with providing instructional kits to support a curriculum matched Grade 5 elementary school science class. The high school students were taught via distance instruction to learn how to engage in 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.). Tier 1 University served as a support team for the project, serving a myriad of roles from troubleshooting technical issues that students alone cannot solve, and providing lessons on Maker practices to incoming students, acting as advisors for electronics purchases necessary for science kit projects. The partnered elementary school class consists of 15 students. Science kits were designed to be used in pairs with the students. During use, components for the kits tend to break (Figure 3). The high school team is charged with producing at least 10 kits for each science topic.

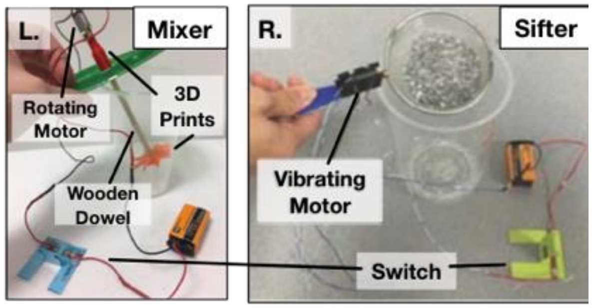

Figure 3 Example of an instructional science

Practically, the study was setup as a career and technical education course. The class provides content that is aligned with academic standards and relevant technical knowledge and skills for current or emerging professions. The course focused specifically on introducing basic technical skills in Making (e.g. basic electronics, 3D modeling and printing, and computer programming). This course provides an introduction to engineering through a series of team-based design projects Students will develop key engineering skills on topics including electrical, mechanical, and software design (Figure 4). In addition, students will practice written and oral communication, teamwork, and management of long-term team-based projects. The course integrates kits developed at Tier 1 University to transform a standard classroom into a fully-functional Makerspace. Students acquire the following skills: 1)The students demonstrate professional standards/employability skills as required by business and industry. 2) Students will be given an high-level introduction to electronics (Ohm's law, bread boarding, resistors). 3) Students will develop an understanding of workshop safety protocols (working with electricity, tools, maintaining equipment). 4) Students will gain familiarity working with analog tools (breadboards,

Technical Skills Outcomes	***Instructional Strategies and Making Skills***
Additive manufacturing	Use 3D printer to print drill bits and dinosaur fossils for the Fossil Excavation Kits
Electronic prototyping	Use Arduino (an open-source platform) to create interactive electronic objects (e.g......), as well as use relays and transistors in circuits to perform simple logic, using Bread Boards
Basic electronics and circuits knowledge	Assemble an LED circuit, design a parallel circuit
Basic LED, rotational & vibrating motor knowledge	Assemble vibrating motors
Electronic Fabrication	Soldering (wires, copper tape, components, pins), crimping, heat shrink
Model and Prototype Building	Build a model with existing resources for a design and feasibility check. Once actual production material is received, build a production prototype.
Chart Preparation	Laminating, creating table charts that the elementary students can understand

Figure 4 Specific Making Skills Learned in Course

multi-meters, power supplies, wires, soldering iron). 5) Students will gain familiarity with digital tools (3D CAD programs, 3D printing).

Year III:

During the third year of the program, there was a challenge in how continuity of the program would take place when parts of the senior class graduates and a new cohort of students to come. We wanted to avoid the HS from repeating the class as before but we wanted to have a means for the incoming class to learn the core practices of making. In response to these issues, we restructured to class in a dual section format, with different learning outcomes and tasks designated for the two classes. The Junior class are students that are new to the program whereas the Senior class are previous participants of the program.

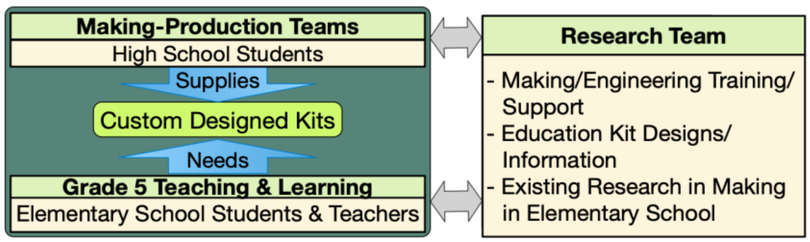

Figure 5 Stakeholders in M² as situated in school district

Students work together as a Making-Production Team (MPT) (Figure 5) in kit production but experience is differentiated between emphasis on either 'Making' or 'Management and Production Engineering' concerns. The Junior class was centered on the issues and practices that are associated with Making. Practically, this is in the actual production of parts for the instructional science kits. Juniors' class experience essentially revolved around the introductory elements of the program. With respect to Seniors, Juniors defer to Seniors for advice and then Tier 1 University team. The senior class was centered on the issues of management and production engineering for the course. In terms of day-to-day proceedings, Seniors engage in kit production but often delegate simpler making tasks to other students or aid them in understanding how to engage in making. Altogether, the seniors pass informal knowledge of the program towards juniors.

Example Week

An example of a typical week can be seen in figure 6. Here, each has roles that are delineated among the three stakeholders (Making-Production Team, Research Team, and Grade 5 Teaching

Week	Day	Date	Module Area	Project Focus	Daily Topic	Juniors	Seniors	Mentor	Teacher	
4	1	8/20/18	Tools and Techniques	Introduction to electronics and circuits	Identity critical tasks and resources for production plan to stay on target. Start production.	0.5	1	Stand by to assist.	Check with students on their plan. Advise them on its feasability.	0 = No involvement, 0.5 = Follows, 1 = Takes lead
4	1	8/20/18	Tools and Techniques	Introduction to electronics and circuits	Use your Gantt chart to estimate how much in advance you need to start	0.5	1	Stand by to assist.	N/A	
4	1	8/20/18	Tools and Techniques	Introduction to electronics and circuits	Assign specific roles/tasks to each person in your team to complete the	0.5	1	Stand by to assist.	N/A	
4	2	8/21/18	Tools and Techniques	Introduction to electronics and circuits	Multimeter, batter and using power supply	1	0	Lead lesson. Have supplies out to demonstrate.	Stand by to assist.	

Figure 6 Example Week Using Dual Tiered Curriculum

& Learning) (Figure 5). At times, Juniors and Seniors have shared or specialized activities per class, as seen in the row 1. In other times, the two student groups engage in separate but still co-situated activities, in which case, Juniors take on manual work whereas Seniors serve more supervisory roles.

V. Findings

Our current iteration of the M^2 program is still in progress with respect to the use of the dual-tiered curriculum. In this section, we will describe preliminary data regarding our curriculum approach. It demonstrates how curriculum design facilitates CoP in students interactions with one another. The data was collected through audio and video recordings of daily class sessions. Class sessions averaged about 40 minutes, capturing the start and end of each day's event. We examined instances of help given and received through a frequency as observed from video data, specifically the first two months of the program for the school year. In Figure 7, with respect to the frequency of help given among members, seniors students contributed the most in helping interactions, followed by teachers, the new students, and the research team (TR). Among the senior students student 1 (SS1) assisted the most (M=58) with student 2 (SS2) following after (M=46). In consideration to who frequently received the most help in class sessions, new students were the most frequent, followed by senior students (teachers, the students when working collectively, and finally the researchers (Figure 8). Figure 9 illustrates the proportion of help given over the initial month of the Year 3, this with respect to all members of the program. Here, what can be seen is that help interactions were fairly frequent the first month but dropping off towards the second month, likely due to the new students gaining familiarity with the

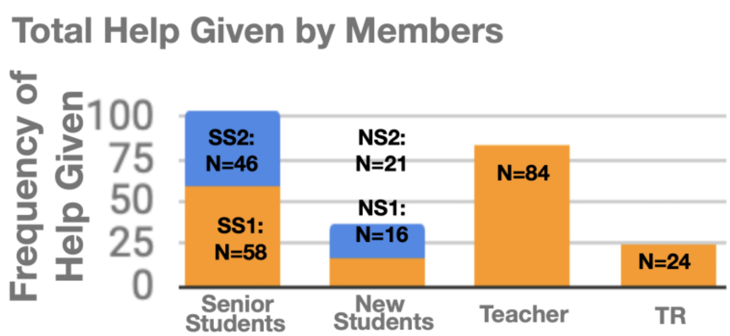

Figure 7 Distribution of help given across stakeholders of program

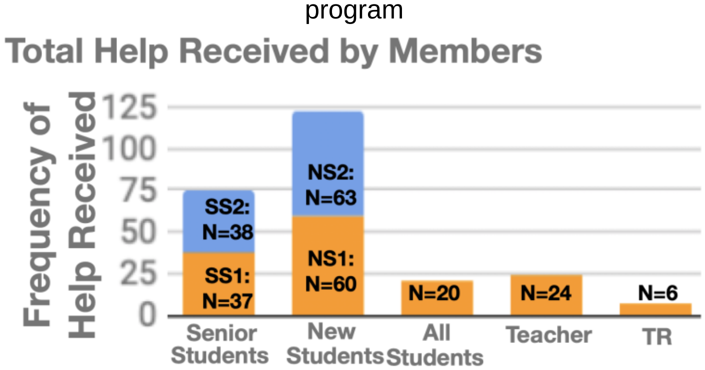

Figure 8 Distribution of help received across stakeholders of program

program. What this segment of data suggests is how a) varying student levels of experience were supported through students b) Teachers and research team serves as a resource for classroom management and information resources, but it is the students who serve as the immediate point

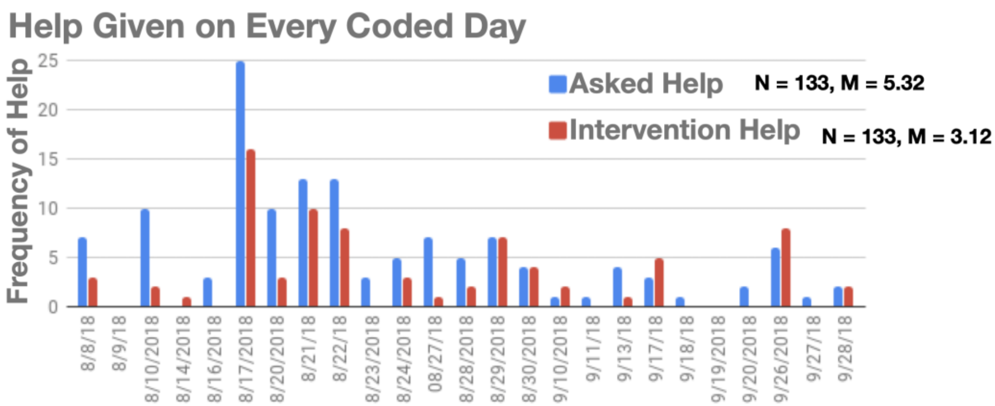

Figure 9 Distribution of help across the first two months of the Year 3

of contact for construction. With respect to a), this could be seen in scenarios where foudational concepts are initially assisted by Seniors but as they become commonplace, 'Juniors' cease to need help with it (e.g., 'Juniors' struggle initially with circuitry and require help but as later work calls for experience, 'Juniors' no longer ask as much help).

A related finding, originating from our video observation, was the extent to which physical co-presence was critical to the proceedings of a CoP in the classroom. In one scenario, the Tier 1 team mentor attempted to troubleshoot an issue that was occuring with the on-site 3D printer. During the 5th week of a given six-week cycle, the 3D printer was malfuncitioning, preventing the production of critical parts for the current kit. Initially 'Juniors' tried to troubleshoot the issue before seeking the help of 'Seniors'. Despite the 'Seniors' experience in troubleshooting, the issue itself required the expertise of the Tier 1 team, going as far as requiring the disassembly of the printer in question to examine it. Despite the availability of telecommunication to provide guidelines, the means to which to overcome the issue ultimately relied on the Tier 1 mentor being physically present to see the issue in high enough detail and guide specifically the means to fix the issue.

VI. Conclusions

In this paper, we presented an application of our "Making as Micro-Manufacture" (M^2) model to address how to STEM participation and learning can be attained in classes of mixed experiences (i.e., students with prior experience in program versus incoming students.

Through this model, we suggested how leveraging 'Senior' students' experience with participation in the model may serve to impart the knowledge and practice to new students when working together in the classroom. While all students are exposed to the Making and production practices in the M^2 model in the class, they are at varying emphasis between 'Senior' and 'Junior' students. 'Senior' students are charged with overseeing production management practices, demonstrating Making skills to 'Junior' students and eventually, delegating production tasks to them. 'Junior' students, through the support of first the 'Senior' students, work with them through the shared production task. Through this task, 'Juniors' are guided by their peers by either troubleshooting problems typically encountered by novice Makers or receiving tacit knowledge that is only made obvious in situated practice. Currently, all students are still in the program. With respect to 'Senior' students, both have applied and have been accepted to undergraduate programs, with SS1 intending to study software engineering at Tier 1 university and SS2 studying business at another in-state university. Junior students have expressed varied levels of interests in higher education with NS1 expressing an interest in pursuing engineering and NS2 still considering options.

What we have presented in our learning curriculum is what Lave and Wegner would characterize as a situated opportunity, that provides the conditions for improvisation of practice, simulating real world practices and concerns (Situated Learning). In such a simulation, this creates a space where learning is situated in s way that is grounded in real world expectations, in which case acting as motivating element to focus on key aspects of practice. When there are asymmetrical relationships in this simulation in the form of the "master-apprentice" relations analagous to that of the 'Juniors' and 'Seniors', it helps to both focus and ground practices in both Making and production, thus facilitating knowledge transfer.

Future work in our program will be focused on the examination of transfer of knowledge across incoming and remaining cohort. In addition, we are interested in examining how co-presence could influence cognitivist learning outcomes for students. How we plan to assess this is through a comparative study where we continue the class with the current HS but also with a HS class that is situated in the same location our university is situated

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