Micro-Manufacture : At the Intersection of Making and Manufacturing

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Abstract

The paper advances a Making as Micro-Manufacture (M3) model where things are made in scales of tens to hundreds in real-world settings and for a real-life purpose. The model combines Making with Engineering concerns attendant to manufacturing at micro scales, and domain knowledge (elementary school science). Practice-based learning in which high school students work in an autonomous Making/Production Team (MPT) is used to initiate students into M3. The MPT work in a scenario simulating professional practice to make/produce instructional hands-on science kits for elementary school students in the same community. This activity requires the pragmatic integration of Making activities with aspects of production scheduling and supply-chain management. The goal is that the MPT members will learn engineering concepts and develop a STEM (Science, Technology, Engineering, Math) self-concept that only such thick practice can provide. The approach is being tested in a rural underserved border community with high school students from populations that are typically underrepresented in STEM.

Author Keywords

Making; Manufacturing; Maker movement; Education; Learning; High school; STEM; Science

ACM Classification Keywords

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

Introduction

In their paper "Escaping the sandbox: Making and its future" describing Making in real-world contexts, Jenkins and Bogost [1] advance the metaphor of a sandbox that highlights the artificial and limited nature of Making for children as it is often currently construed in Maker workshops, summer camps, and after-school programs. In their analogy, Making is like a sandbox in which children play on a well-manicured lawn. As long as the sand stays within the box, it is useful.

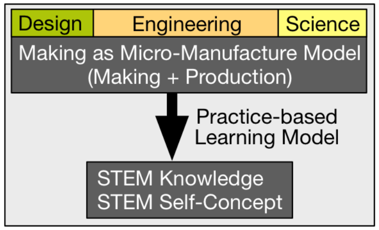

Figure 1. M^3 learning model

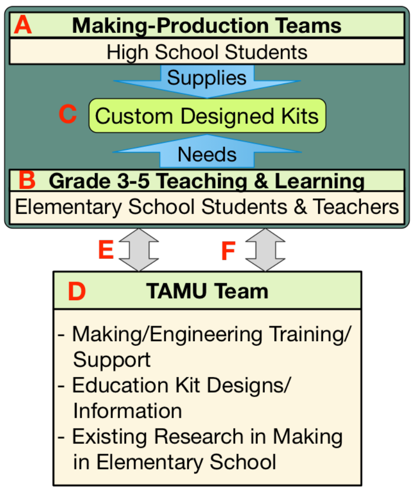

Figure 2. General project model

However, if the sand spills onto the lawn, it is unsightly dirt that contaminates the well-mown grass. The plethora of Making kits and structured projects designed to encourage Making activity often have the undesirable effect that Making becomes an insular activity where it is hard to see how the skills acquired may be applicable beyond the circumscribed world of the specific Making activities. We posit that this insularity also makes it difficult for participants to see how the Making activity is relevant to their everyday lives and how it supports their future endeavors, thereby minimizing any benefits that Making has been reported to have in education.

We propose a model of **Making as micro-manufacture (M^3)**, whereby *one makes things in scales of tens to hundreds in a real-life situated scenario and for a real-life purpose*. Figure 1 illustrates our general learning/identity development model built around M^3. The model combines Making, Engineering, and domain knowledge, with practice-based learning to support STEM learning and the development of a STEM self-concept in high school students. This resonates with the very nature of Making that emphasizes empowerment and cumulative knowledge and skill. We are engaged in an ongoing two-year study of high school students in an autonomous *Making/Production Team* (*MPT*) to make/produce materials for instructional hands-on activities for elementary school students in the same community. The elementary school materials are being designed along with a set of curricula for the 3rd to 5th grade classrooms in another 3-year longitudinal program [2-4]. We have found that the making of these materials requires the significant pragmatic integration of Making activities, such as electronics and 3D fabrication, with aspects of production scheduling and implementation, and supply-chain management. We anticipate two outcomes in our research. First, the MPT members will learn the technical knowhow related to making and producing the instructional materials through an apprenticeship-inspired and practice-based training process. Second, by engaging the MPT members in the practice of Making and production, we will impact the self-efficacy of the team members as individuals engaged in engineering, and encourage self-identification as possible future engineers. Our project engages high school students and the local elementary school in a *Colonia* community along the southern border of Texas. Such communities are typically under-resourced and economically distressed, and severely under-represented in STEM education and careers. Hence, our M^3 project represents a sustainable and scalable model for how micro-manufacture may support the needs of isolated rural communities.

Project in a Nutshell

Figure 2 illustrates our general project model. The top of the figure shows our target communities that include (**A**) the MPT comprising six high school students from the community, and (**B**) the rural elementary school that serves as the consumer of the instructional materials (the Custom Designed Kits). The proposed project will leverage our ongoing program [2] that is developing (**C**) Custom Designed Kits that are paired with elementary classroom curricula. The curriculum needs of the elementary school furnish the MPT with real-world practical requirements and deadlines that have to be met. For example, to cater for the number of students in the elementary classrooms, each elementary curriculum segment will need to have multiple copies of a particular kit design. The MPT has to engage in the entire Making/engineering task chain from prototyping, parts acquisition (supply

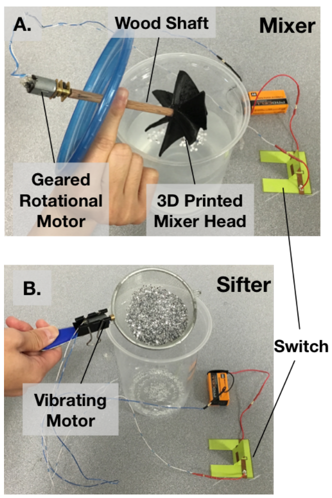

Figure 3. Mixer and Sifter kit for the "Mixtures & Solutions" curriculum segment

chain and industrial distribution), manufacture planning (human resource scheduling/management, production planning), electronics and mechanical prototyping, and client relations (working with elementary school teachers). Over time, the MPT members will acquire 'thick knowledge' about general technical/technological knowhow that can only be obtained from situated experience.

The right side of Figure 2Figure 2 illustrates the training and support mechanisms for the Colonia participants. Our university team (**D**) leverages the knowledge and experience gained from our ongoing program [2] to support the high school MPT through site visits and through teleconference (**E**). We also provide support to the MPT to coordinate and liaise with their local elementary school teacher for the development and deployment of the elementary school Making-based curricula and projects (**F**).

Model of Making as Micro-Manufacture (M^3)

The manufacture at micro scales of hundreds of units requires the involvement of various engineering disciplines, business and management, education and pedagogy, government and policy, human and social systems, and the arts and design. M^3 escapes the Making sandbox to enable real-world flexible and efficient short-run manufacturing. Making has been defined 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], as a "new paradigm of hacking as formation of creative communities with alternative lifestyles rooted in emergent technologies and innovation" [6], or as "the production of anything tangible, from producing a sketch to the generation of fully manufactured objects" [7]. The current understanding of Making however is thus akin to 'boutique manufacturing' that focuses on the production of high-end one-of-a-kind products. Because boutique manufacture does not require repetition, products are typically made manually thus combining artisanship with limited automation [6]. *While the model of M^3 maintains all aspects of current Making, it adds concerns attendant to manufacturing at micro scales.* Issues of concern include scaling and repetition, modular design and cellular or flexible processes, resource management, etc.

An example of an instructional kit that the MPT may produce for the elementary science curriculum topic of 'Mixtures and Solutions'. This kit requires the assembly of a mixer that comprises a geared rotating motor that drives a 3D-printed mixing head through a 0.25" diameter dowel rod, and a mechanical sifter that comprises a vibrating motor attached to a hand sifter (Figure 3). Each motor requires a paper-based switch and connectors to a 9V battery. Each kit requires the construction of 4 paper switches, 16 solder junctions (2 per motor and 2 for each switch), and 12 custom plug-in connectors. If each paper switch takes 10 minutes to make, each solder joint takes 30 seconds, and each custom connector with wire and shielding takes 4 minutes, one kit will take ($[10 \times 4] + [16 \times 0.5] + [12 \times 4] =$) 96 minutes to assemble the electronics parts. If the mixer head needs 45 minutes to print, the dowel rod shaft takes 30 seconds, and the sifter needs 3 minutes to set up, the total assembly will take (96 + 45 + 0.5 + 3 =) 144.5 minutes. For a class of 20 elementary school students working in pairs, the total assembly time amounts to (10 x 144.5 minutes =) 1445 minutes or 24.1 hours. Adding an overhead of 2 hours for kit assembly, this will come to a grand total of 26 worker-hours for the assembly alone. This excludes the time it takes to set up the production, assemble parts, manage inventory, and recover the materials for later reuse. The purchasing requires cost-effective material acquisition to ensure that the kits will be ready for the classroom in time. Furthermore, given the variability in components available from vendors, kit sub-assemblies have to be prototyped and tested. Hence the MPT has to engage in the entire engineering task chain, as well as customer relations (working with the elementary school teachers).

The domains of skills and knowledge that the M^3 model encompasses within our framework of high school students manufacturing instructional elementary school science kits include design thinking and prototyping, manufacturing and industrial distribution, and elementary science concepts. With respect to design, the MPT needs to engage in such practices as iterative design, basic ideation techniques, paper and dynamic prototyping, tinkering, physical computing, virtual modeling, user-centered design, etc. With respect to manufacturing and industrial distribution, the engineering task chain that the MPTs engages involves the concurrent planning and implementation of all aspects related to material/parts acquisition (supply chain and industrial distribution), personnel (human resource scheduling/management), production and distribution. Specifically, this consists of the manufacture of mechatronic component assemblies in high-variability low-volume batches (in the hundreds)

Conclusion

We presented a model of Making as Micro-manufacture that combines the processes of Making with the requirements of manufacturing products in small quantities of hundreds to thousands. In an ongoing project, we are employing this model in an educational setting where high school students engage the thick practice that supports learning that spans design, prototyping, manufacturing and industrial distribution. Beyond the education context, we anticipate that micro-manufacture in conjunction with Making may enable entire new industries of local production that has significant social implications.

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