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Design and Preliminary Evaluation of a Deployable Mobile Makerspace for Informal Additive Manufacturing Education

Swapnil Sinha[1], Kelsey Rieger[2], Aaron D. Knochel[2], and Nicholas A. Meisel[1]
[1]Made By Design Laboratory
School of Engineering Design, Technology, and Professional Programs, Penn State
[2]School of Visual Arts, Penn State

ABSTRACT

Additive Manufacturing (AM) has played an integral part in the growth of makerspaces as democratization of manufacturing continues to evolve. AM has also shown potential in enabling the successful amalgamation of art (A) with science, technology, engineering, and math (STEM) disciplines, giving new possibilities to STEAM subjects and its implementation. This paper presents the conceptual design and development of a deployable, mobile makerspace curriculum focused on AM education for a diverse range of participant backgrounds, ages, and locations. The aim is to identify effective means of informal learning to broaden participation and increase engagement with STEAM subjects through the context of AM. The curriculum is envisioned as "material-to-form," offering separate modules that present opportunities for self-directed learning through all the stages of design, material use, and manufacturing associated with AM. Pilot studies of the curriculum were performed to identify potential changes to improve the effectiveness of the mobile makerspace.

1. INTRODUCTION

The rapid expansion of low-cost additive manufacturing (AM, or 3D printing) systems has been one of the key catalysts in the rise of the maker movement. This movement is typified by a student desire to learn through hands-on design and fabrication experience, which maintains a primacy on sharing, connecting and do-it-yourself tinkering [1], [2]. Often, this experience occurs in increasingly common makerspaces, whether academic or commercial in nature. While makerspaces are often comprised of various forms of manufacturing (numerical milling machines, laser-cutting, welding, electronics manufacturing, etc.) many modern makerspaces also incorporate some form of AM. AM's capacity to quickly and accurately manufacture parts of nearly unlimited complexity with minimal manual user input positions it well as a key element in learning through making. Indeed, research has shown that makerspaces are the dominant location where the majority of entry-level AM occurs [3]. However, the same research discusses that, while the spectacle of the printing process often lures users to the various systems, users may maintain only a superficial or passing interest in the technology, if not encouraged to experiment with the complex relationships between the AM process and the designs that can be manufactured with it.

One of the defining traits of the maker movement is that it is inherently interdisciplinary. This allows it to organically operate at the intersection of science, technology, engineering, art, and math (STEAM) disciplines. STEAM initiatives may provide an opportunity to actualize a resurgence of the fundamental importance of making to learning. This resurgence can be seen in the energy around digital media and learning [4], [5] and in the growing prominence of the maker movement. Increasing success of STEM students is connected to creating experiential learning opportunities. While this experiential emphasis can take many forms, utilizing interdisciplinary approaches to complex problems that draw upon STEM inquiry methods has had positive impacts on students' self-efficacy [6]. Recently, there has been a call from federal legislatures for "*re*integrating the two [STEM and Art disciplines] in our classrooms" [7], but the lack of substantive funding continues to marginalize initiatives in STEAM as a low priority [8]. STEAM has gained momentum as it is taken up in the popular press as a conundrum for educators [9], as a way of merging art and science education [10], and a way to "encourage holistic learning" [11]. The National Science Teachers Association (NSTA) reports incorporating Art into STEM subjects is a benefit to students and teachers in connecting concepts, exploring ideas, and increasing participation [12]. Indeed, research from the NSF funded The Art of Science Learning initiative indicates that student participants benefited from arts-based learning via greater collaboration, increased creative thinking, and longer sustained benefits in school and extracurricular participation [13].

To address the opportunities inherent in utilizing makerspaces to promote informal STEAM education, this paper discusses the creation and pilot implementation of a mobile makerspace (dubbed MAKE 3D) that capitalizes on the spectacle of AM to promote design and manufacturing learning. The system will ideally improve informal learning pathways for increasing retention and broadening participation in STEAM for students. Section 2 will discuss existing research into both the educational context to support makerspace learning as well as existing forms of AM curricular spectacle. Section 3 will then detail the design of both i) the mobile makerspace itself as well as ii) the curricular elements that scaffold the student learning experience. Section 4 will offer both quantitative and qualitative evidence of the makerspace's impact on student engagement. Finally, Section 5 will offer conclusions and discuss avenues for future research and implementation.

2. LITERATURE REVIEW

Related research relevant to this work has been divided into two sections. Section 2.1 discusses the emphasis on education to expand the field of AM and the close alignment of the maker movement to introducing informal contexts of AM to the formal context of schools. Section 2.2 discusses existing development of mobile makerspaces through informal contexts such as libraries, hospitals, and museums.

2.1 Educational Context to Support Informal Learning with the Maker Movement

The "2009 Roadmap for Additive Manufacturing" identified education as a critical area of research and development for advancement of the additive manufacturing field [14]. To address this critical area there have been efforts to explore AM primarily focused on university and industry training [15], but there is also interest in curriculum at the secondary level [16]. In order to grow AM learning, it is crucial to intertwine interdisciplinary curricula with simultaneous hands-on manufacturing experience. Increasing success of STEM students is connected to creating experiential learning opportunities [17]. Makerspaces provide a set of tools within an informal context that maintains a primacy on sharing, connecting and "thinking through materials" [18].

Makerspaces also are perceived to have a high level of engagement for students within an informal setting. Formal contexts, such as schools, are disconnected from students' everyday lives and not focused on what students necessarily want to learn [19]. However, makerspaces are increasingly becoming a part of schools creating more fluid boundaries between formal and informal contexts for education [20]. Makerspaces provide student-centered learning environments that integrate technology and material play engaging more students to find value in school [21]. When students create with technology they "become more engaged, spend more time investigating and/or constructing and take ownership for and build confidence in their abilities to learn and understand" [22]. Part of what creates engagement in the makerspace context is the importance of creativity and play with materials, often expressed through the concept of tinkering. Tinkering is an open-ended process of inquiry that involves improvisation and creativity [23].

2.2 Existing Forms of AM Curricular Spectacle and Mobile Makerspaces

Makerspaces combine informal learning utilizing AM as a central fabrication technology, interdisciplinary approaches in STEAM, and investigations into materials, but are often situated within a particular space, which limits their impact. MAKE 3D adds an additional aspect through the mobility of our platform extending what we call the curricular spectacle of our approach. Curricular spectacle refers to educational efforts that involve highly visible or novel introductions to content or technologies that engage learners immediately while possibly leading to deeper understanding. Attempts in recent years to capture this spectacle-driven fascination with AM technology to informally guide users to a deeper understanding of manufacturing and design include MakerBot Innovation Centers and 3D printing vending machines [24]. Beyond these static forms of informal AM making, libraries, universities, and K-12 schools have also been experimenting with the use of mobile makerspaces to create a sense of spectacle that can be easily transported from location to location (see, for example, [25]–[28]). While these mobile makerspaces have been shown to excite local communities and create a sense of wonder regarding AM technology, there have been no studies to assess whether or not such mobile makerspaces are capable of taking the user's initial spectacle-driven fascination and sustain it into learning and engagement with the STEAM disciplines that rely on the concept of making.

Research on informal learning and makerspaces has demonstrated its import for science education [29], [30], and much of this work in informal spaces has focused on libraries and museums [31]–[33]. Library programs such as the Arrowhead Library System mobile makerspace, started in 2014, to develop a model of shared equipment relevant for making among seven small to mid-size libraries in southern Wisconsin (see http://als.lib.wi.us/Makerspace/). There has also been mobile making in hospitals to explore its therapeutic capacity such as Gokul Krishnan's mobile makerspace at Monroe Carell Jr. Children's Hospital at Vanderbilt in Nashville, Tennessee [34] which helps to address the needs of chronically ill patients (see http://www.makertherapy.com/). All of these programs are engaging with issues of maker education in ways that is mobile, open, and accessible to all. Our research is intended to add to this literature with the unique capacities of mobile makerspaces with adaptable curricular kits that engage learners in design and material education using AM to extend this high-visibility approach and better understand the effects of heightened awareness, hands-on learning, and broader participation in making as an experiential approach to STEAM disciplines.

3. DESIGN APPROACH TO THE MOBILE MAKERSPACE

The essence of a mobile makerspace lies in its nature of being accessible, both physically and intellectually [35]. Just like the mobile libraries or the bookmobiles which were introduced to provide library services everywhere [36], the mobile aspect of a makerspace ensures the physical accessibility of a learning environment. Additionally, a self-driven and experiential learning offered by these makerspaces is expected to improve participation in STEAM [37]. Subsequently, the MAKE 3D truck is intended to be built so as to offer effective learning and retention of knowledge offered around AM. To meet this objective, the design of the trailer dedicated as the mobile for this deployable makerspace, and its operation is elaborated in the section 3.1. The development of the curriculum for the same is explained in the section 3.2.

3.1 Overview of the MAKE 3D Space and Educational Approach

The entirety of the deployable MAKE 3D makerspace is contained within a single mobile platform. The platform chosen for this implementation is a closed-wall trailer (see Figure 1) with interior space of 132” x 72” x 78”. The different equipment, consumables, and support systems necessary to operate the makerspace were custom designed and selected in order to best make use of the mobile environment. When the MAKE 3D trailer arrives at the desired location, all contents can be removed and deployed in a flexible configuration. This allows it the unique ability to have the learning space cater to the needs of the student, rather than requiring the student to conform to the limitations of the learning space.

(a) (b)

Figure 1. MAKE 3D trailer with (a) side view, and (b) back view.

The curriculum for MAKE 3D was developed with the intention of introducing AM in a makerspace platform to test and advance its role in improving the effectiveness of informal learning pathways. Via a comprehensive spectrum of rudimentary concepts referred to in this project as the “Material to Form” model, the curriculum for MAKE 3D centers around AM as a fabrication method in making from an interdisciplinary and layman understanding. As the term “material to form” suggests, the curriculum for MAKE 3D was originally conceived of as a comprehensive project with a clear start-to-finish trajectory. However, given the nature of the makerspace as an informal learning resource for voluntary learners and the project’s interdisciplinary platform, it became apparent that the materials and curriculum would need to be accessible from multiple entry points. As such, each learning module required flexibility to address varying expertise, learning styles, time constraints, and levels of interest. This is done through various demonstrative pieces that invites participants to try on hands-on activities that emphasizes design and inquiry-based methodologies like Design Thinking [38] as integral components of making. Throughout the development of the MAKE 3D project, the Material to Form curriculum has gone through multiple iterations informed by ongoing pilot studies. It was determined early on that these elements could be grouped into six categories of modules in the curriculum, based on the application and equipment required. The modules included **Designing Form, Modeling Form, Capturing Form, Workflow in AM, Extrusion, and Filament Variety.** These modules will be discussed in more detail in Section 4.

Each module was initially developed as self-contained units from start to finish, in order to keep in facilitate a more non-sequential and informal flow of participants through modules. Additionally, each module was developed with its own set of equipment, a handout, and a set of slides. In the early stages of development, equipment for each module includes all the possible hardware, software, and the exemplary relevant 3D printed pieces to be included in a makerspace station. As the build of the makerspace progresses curricular modules were expressed in makerspace stations with some overlap. For example, the Capturing Form and Workflow in AM curricular modules are both facilitated in the makerspace computer station. Handouts include sets of directions for activities for each module in step-by-step screen shots and short sentences, ending with reflection questions prompting participants to think about what they learned through the activities (see Figure 2). Finally, slide shows were created for each module as an additional resource for the instructor to help explain concepts, if necessary. However, in order to maintain the informal nature of the approach, slides are maintained on individual tablets, rather than projected on a large screen for the entire group.

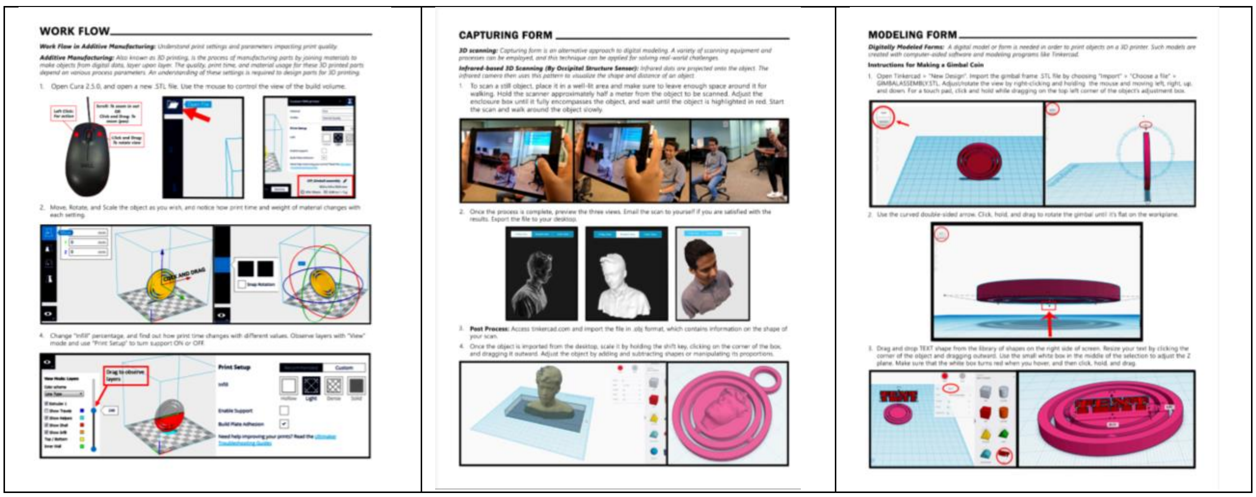


Figure 2. Examples of handouts in the Work Flow, Capturing Form, and Modeling Form modules

A gimbal design (see Figure 3) was created to serve as a base example for the activities in all six modules. This geometry serves as a tool to provide scaffolding for student learning throughout the makerspace. The gimbal is defined as a pivoted support that allows the rotation of an object around a single axis, and thus requires participants to consider its aesthetic and functional aspect. [39]. This assisted in keeping the modules tied to each other, creating a flow between them. For example, geometry serves as a base of Design Form module by prompting students to think and create other forms of gimbals, it also serves as a base for Modeling Form to modify it in the digital platform, etc. A common article, like the gimbal, is expected to provide participants with a motive to proceed to other modules, by introducing the possibilities of variations that can be performed on it. The gimbal was chosen because of the spectacle it offered with its function. Its fabrication with 3D printing as an assembled part in one build adds an additional wonder to the possibilities of AM, which may invite curiosity and consequently self-motivated involvement in the modules.

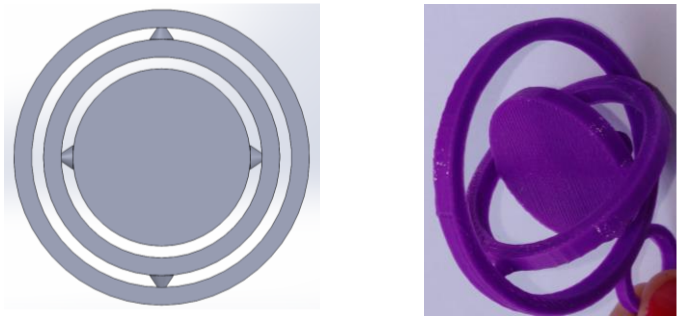


Figure 3. Gimbal design created as a common artifact for continuity between curricular modules.

3.2 Details of Individual Educational Modules

The aim for MAKE 3D is to provide hands-on learning experience in AM to a virtually unexposed group of students. To successfully create a platform providing basic understanding of AM, the curriculum was built around the equipment providing demonstrative, and free form interaction. The curriculum covers design thinking, digital designing, digital capturing or scanning, work flow in AM (from conversion of files into .STL format to slicing it for desired part quality), extrusion (with 3D pens and clay extruders), and filament variety available. These elements were disseminated into different modules according to the hardware and software utilized, and are elaborated below.

<u>*Designing Form*</u>

As the only learning module not directly tied to a particular element of AM machinery, designing form is a creative prototyping activity based on the process of Design Thinking [38]. The conceptual foundation for this module is based on the understanding that design is an iterative process, which can be strategically performed using the five design thinking stages. These stages are: empathize, define, ideate, prototype, and test. From the activities stipulated in the Designing Form curriculum, MAKE 3D participants learn to use this creative and critical process to effectively design a personalized product, such as the gimbal coin discussed earlier. To support participant engagement with this process, nontechnical materials such as cardboard, scissors, and tape are used for the prototyping process. Participants begin by sketching various versions of their design (see Figure 4), before creating cardboard rotating prototypes in the form of their initial design. The Designing Form module was set up as an individual station that includes all the necessary prototyping supplies and tools.

Figure 4. A participant engaged with Designing Form handout, creating gimbal inspired designs and participants engaged in prototyping.

Modeling Form

The digital modeling component of the curriculum integrates opportunities for experimentation with available programs such as Fusion 360 (https://www.autodesk.com/), Tinkercad (https://www.tinkercad.com/), and SketchUp (http://www.sketchup.com/). Each of these platforms were considered to determine the most user-friendly and accessible program available for MAKE 3D participants to engage in designing new forms. Tinkercad was ultimately chosen for the makerspace due to the fact that it is free to the public and promotes a simplified, straightforward set of commands. This module provides participants with the opportunity to learn by doing, and may or may not be based on their previously prototyped gimbal design depending on preference and interest (see Figure 5). The handout guides them to create a personalized keychain by importing an existing gimbal design and modifying it. The directions aim to create an understanding of spatial orientation in digital design, and how to manipulate it to create desired designs. The Modeling Form module was setup along with the Work Flow module as a grouped station, since both requires computer for hands-on activities. Six computers were setup on a table of dimension 72" x 32".

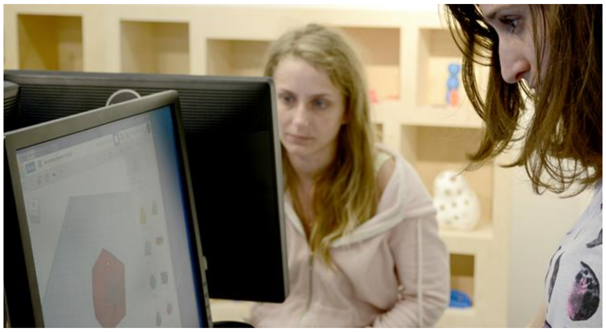
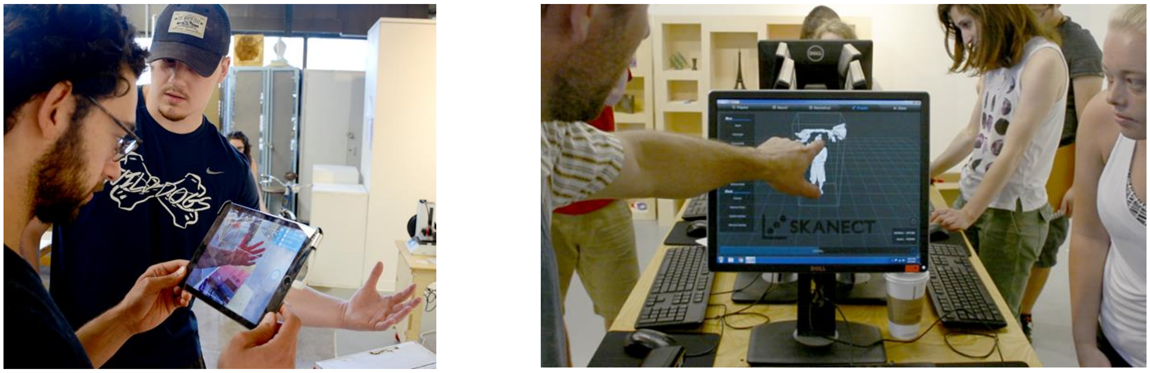


Figure 5. Use of computer station to learn digital design in Modeling Form module.

Capturing Form

Similar to Modeling Form, the scanning equipment provided in the Capturing Form Module is meant to offer participants the opportunity to engage freely with available technology in order to better grasp its capabilities. This engagement occurs via Occipital Structure Sensors on iPad, SCANN3D application for android phones, and Microsoft Kinect Scanner programs that are demonstrated for the students prior to use. This hand-on engagement allows participants to directly observe how 3D scanners are able to capture surface data to be converted into a printable .STL file (see Figure 6), and to educate participants in the area of mass customization as one of the driving forces in design for AM. The Capturing Form module was set up as an individual station, with the Structure Sensor and the Kinect on a small table. A rotating turntable of diameter 32" was constructed as a scanning rig for a hands-on good quality 3D scanning with Kinect. One of the computers in the modeling form and workflow station was dedicated for the Kinect scanning.



(a) (b)

Figure 6. Scanning station with equipment in use (a) Structure Scanner being used by the participants to scan a hand, (b) Experts demonstrating use of the turntable to obtain a good quality 3D scan with Kinect.

Work Flow in AM

The Work Flow module focuses on the print preparation procedure from importing the digital design in STL file formats to exporting the 3D print-ready file. This module demonstrates the different parameters in the slicing software (*Cura*) that can be varied to create the desired output. It prompts participants to think about considerations like support material, infill densities, layer thicknesses and their impact on part quality and total time for print. The layer animation of the previewed file demonstrates the layer-by-layer addition of material in AM, explaining the capability of fabricating complex part. The workflow module also incorporates demonstrative 3D printed objects to show the need for support material, layer thicknesses, infill densities and patterns, and various slices of an object printed as a stacking puzzle game. This module introduces participants with the restriction as well as opportunities of AM, an important aspect to be considered while designing for AM.

Extrusion and Filament Variety

Material extrusion systems in the form of 3D pens, handheld clay extrusion tools, 3D printers, and filament extruders are leveraged alongside 3D printers using both clay and plastic filament. The inclusion of a filament extruder also provides an initial introduction to the concept of raw material processing within AM. This simple system demonstrates the ways in which plastic pellets are heated, extruded, and wound around a spool to form the processed material for material extrusion AM (see Figure 7). These materials are used in collaboration with an information handout and worksheet to allow participants to directly observe the manufacturing phase for their designed products by relating the complexities of their chosen design to the capabilities of the manufacturing system. Furthermore, these materials help participants conceptualize the physical capabilities of the 3D printer and the potential for expanding the X, Y, and Z planes of a two-dimensional object. Along with the learning goals of the Workflow Module, these curricular materials engage participants in the process of producing a three-dimensional object using variety of materials with AM. The hands-on involvement helps in the most effective demonstration of AM extrusion process behavior with different materials like metal, wood, flexible filaments, and conductive materials. Extrusion module and the Filament Variety module was set up together on a table along with the 3D extrusion Pens and the clay extruders. Various filaments were available for use with 3D extrusion Pens. Multiple material extrusion printers were setup together along with a demonstrative clay printer.

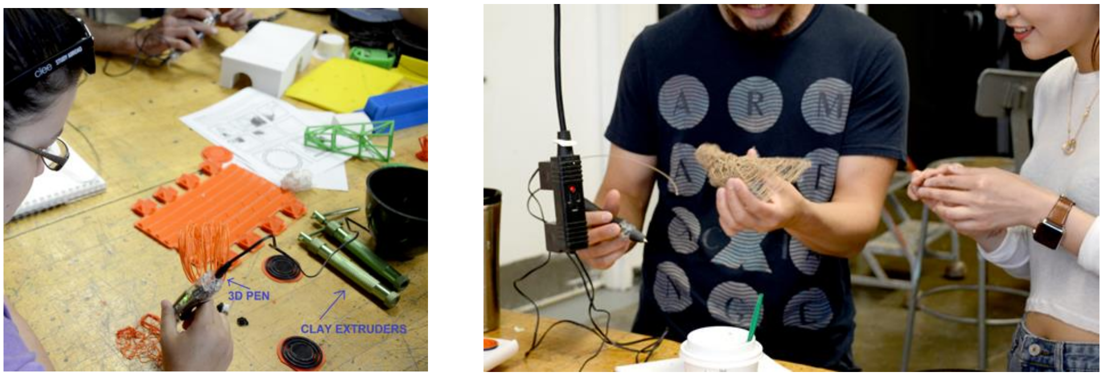


Figure 7. Participants creating 3D objects with 3D Pens at extrusion station, playing with different filament variety.

Demonstration Gallery

Finally, while not a formal curricular module, a Demonstration Gallery (see Figure 8) was conceived to add a collection of 3D printed items, which acted as the demonstration for each module. This gallery acts as a curated collection of engineering design, science, mathematics, and art objects in a range of printed materials that are meant to illustrate the wide variety of potential part applications, surfaces, densities, and AM capabilities. Objects included in this gallery are considered case studies, acting as examples of the themes found in each of the established learning modules. Due to the open source nature of much of the maker culture, all of the works featured in the gallery include corresponding .STL files and resources for reproduction that are accessible to the participants and the general public. While all these modules were developed around material extrusion process in AM, owing to its simplicity, accessibility, and robustness for an educational setting, the other major process types in AM are demonstrated in form of example prints showcased in the Demonstration Gallery.

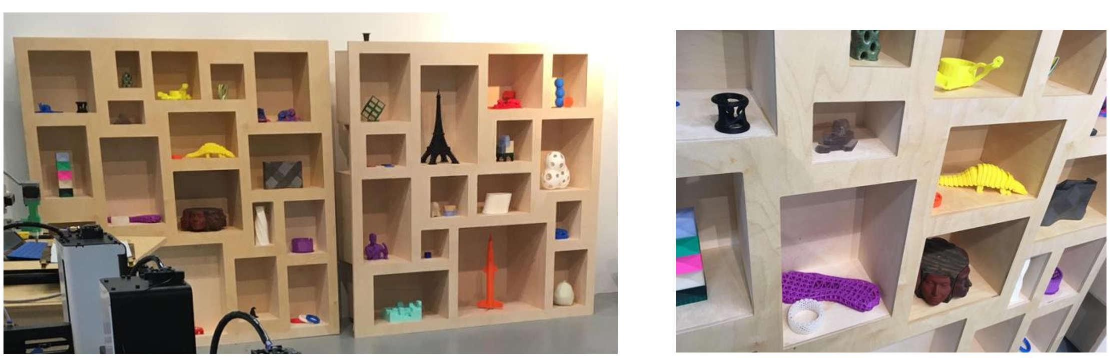


Figure 8. Examples demonstrated in the Display Gallery

4. PRELIMINARY USAGE CASE STUDY

To test the applicability of the curriculum and the equipment developed for the MAKE 3D, a pilot study was performed on four undergraduate class sections, each comprised of approximately 24 students. The aim was to observe the functioning of each module as an individual station, in terms of interaction by the participants, and the involvement of instructors. Additionally, the effectiveness of the curriculum in boosting participant's comprehension of makerspaces, design thinking, and AM technology was observed.

4.1 Educational Context

For the pilot studies, a room was setup as a preliminary mock-up of the deployed form of MAKE 3D with all the six modules in the curriculum setup as stations (see Figure 9 and Figure 10). The stations were grouped as explained in Section 3.1, according to the equipment requirements and named as Designing, Computers, Extrusion, Scanning, Printing, and the Gallery for data collection purposes. While Designing, and Scanning were individual stations for the Designing Form module and the Capturing Form modules, respectively, the Computer station was a combined setup for the Modeling Form and Work Flow modules. Similarly, the Extrusion station was a combined setup for Extrusion module as well as the Filament Variety module. The printing station consisted of five material extrusion printers (Monoprice Mini) for free use by the participants, as well as a clay printer for demonstration. The Gallery station was named for the gallery display. Each station included packets consisting of the collected handouts for all modules, with posters at each station also included to convey the same information in a larger format. Experts in AM informally moved between stations to guide or demonstrate concepts or equipment to the participants if required.

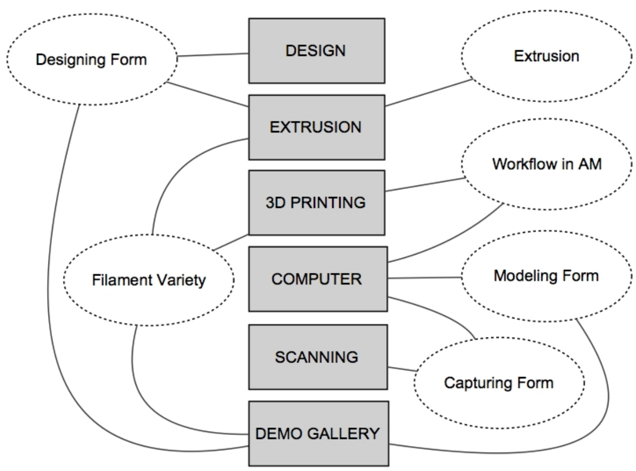


Figure 9. Conceptual arrangement of the deployed MAKE 3D set up for pilot study, with connections between physical stations (rectangles) and corresponding modules (ovals).

Figure 10. A portion of deployed MAKE 3D makerspace stations present at the pilot studies.

Before exposure to the deployed MAKE 3D space, the participants were prompted to self-rate their agreement on familiarity with makerspaces, 3D printing, and design thinking, etc. on a Likert scale. The participants were given a short premise of MAKE 3D as a makerspace, before the exposure. Two raters individually and simultaneously completed observation sheets with a narrative description of what they perceived was the participant's response and reaction to each station every 10 minutes from the beginning to the end of the session. Additional data for number of participants and their nature of interaction with the module was also collected for each station. Each session lasted for approximately one and a half hours.

4.2 Results

The age of the 95 participants ranged from 17 to 20, (15 females and 80 males). These participants were all students participating in an introductory engineering design course targeted at first-year engineering students. The participants were asked to finish a 20-question survey on a Likert scale (see Figure 11) right before their exposure to makerspace. The same survey was taken right after the exposure. A sign test with continuity correction was used to compare differences in the Likert scale for each question, pre- and post-exposure, using IBM SPSS Statistics 24.

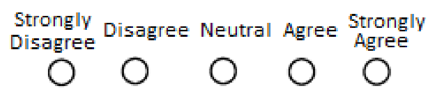


Figure 11. Likert Scale as provided to the participants for each question, pre and post-exposure.

The mean values of the participant ratings improved for 19 of the 20 survey questions post exposure, compared to their pre exposure data. To find the significance in improvement, statistical analysis was performed within subjects. On statistically analyzing the pre-exposure and post-exposure student surveys for the same 20 questions, a statistically significant increase was found for 10 of the 20 questions (questions with a significant increase are shown in Figure 12). Three questions in particular saw drastic improvement. First, it was found that students rated themselves statistically significantly more familiar with concepts of a makerspace post exposure, ($p<0.0005$, increase from "Disagree" to "Agree"). This metric gives us a self-reported engagement with MAKE 3D as a complete system, where a significant improvement in rating indicates a good level of engagement in the space. Students also rated higher on use of 3D printing, post-exposure, compared to pre-exposure ($p<0.0005$, increase from "Neutral" to "Agree"). The jump from neutral to agreement means that the makerspace is properly executing one of its main goals: offering students a chance to go hands-on with 3D printing technologies in order to improve their engagement with this technology. Additionally, a significant increase was reported in the students' understanding of 3D scanning technology ($p<0.0005$, increase from "Disagree" to "Agree"). Similar to the use of printers, this jump from disagreement to agreement indicates that the curriculum was able to showcase the use of 3D scanning in a way that is relevant to the participants.

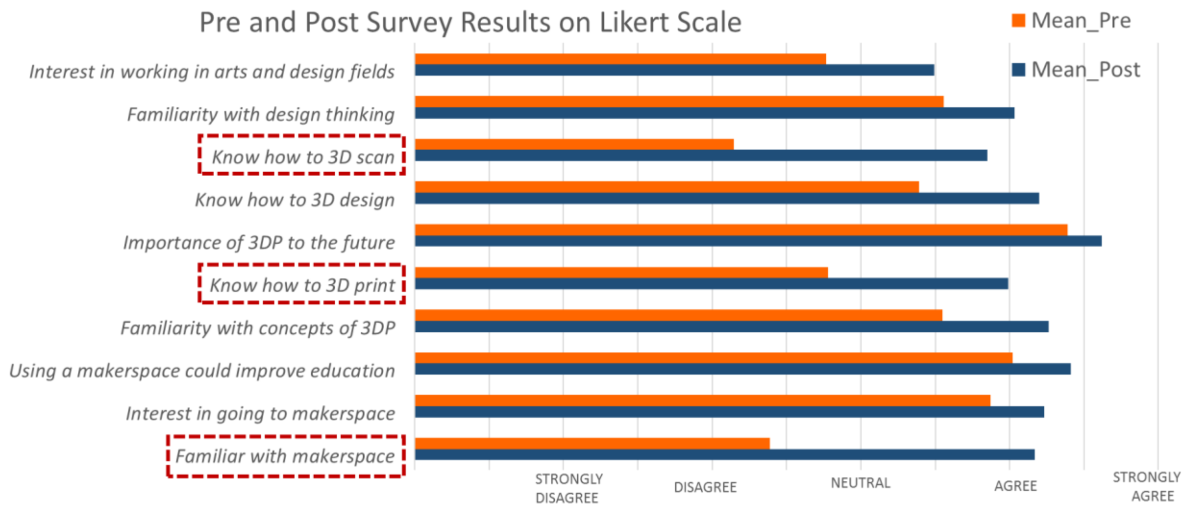


Figure 12. Average Likert scale rating for survey questions with a statistically significant change between pre- and post-exposure. Questions with the most drastic changes are highlighted on the vertical axis in a box.

Two observers simultaneously recorded the descriptive narration of what they observed in each station in every 10 minutes. They recorded the number of students at the station, and overall engagement in the scale of 1 to 5, and type of interaction with the modules for each station. Reliability for the engagement level rating scale from two Raters at each station was found by calculating Chronbach's alpha. The test was performed with IBM SPSS Statistics 24, on data points with common time and common number of participants. The test revealed high reliability of the scale with Chronbach's alpha equating to 0.96. On observing the average for the ratings obtained from the two raters on engagement, it was found that the computer station with the Modeling Form module was the most engaged station, followed by the extrusion station with 3D pens and clay extruders with variety filament, further followed by Printing, Design, Scanning, and the Gallery stations respectively (see Figure 13). Additionally, it was observed that extrusion had the highest count of participants every 10 minutes followed by Computer, Printing, Design, Scanning, and Gallery respectively.

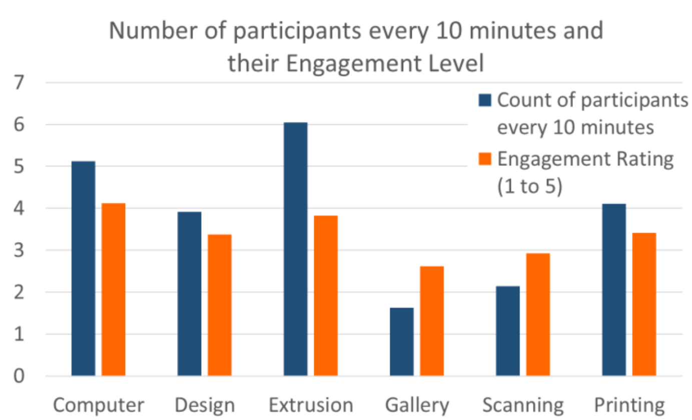


Figure 13. Average engagement rating by the raters for each station, along with the average count of participants every 10 minutes in each station.

Observation notes support the engagement ratings in clearly highlighting the popularity of the extrusion table often citing freeform design with the 3D pens and even extruding designs onto objects such as smartphone cases and older discarded prints that were made available. Peer interaction and numbers of participants remained high throughout the session suggesting the success of the informal environment of tinkering, but uncertain as to how the module connected with or motivated students to move to other stations to work on other curricular modules. Observation notes also confirmed that participation at the computer station appeared to be longer term for certain users as it was noted that participants would stay on the computer station designing 3D forms in Tinkercad for long periods of time which relates to both levels of engagement but also the time intensive practice of 3D modeling. It is unclear as to how the computer station related to other modules, because there were observations indicating that participants were progressing from designing form to utilizing the 3D printing workflow to prepare their prints. However, improper build profiles loaded on the 3D printers would sometimes hamper the production of prints and made it difficult to track this production cycle. Observation notes indicating low participation in the Design and Gallery stations highlighted the inadequate curricular supports provided in the paper handouts and lack of instruction for each module to provide entry points to making at the various makerspace stations. Revisions to the makerspace and curriculum will take these considerations into account as we make changes for subsequent deployments.

5. CONCLUSIONS AND FUTURE WORK

The MAKE 3D mobile makerspace is conceived as a platform for individuals to gain hands-on experience with AM technology. It is built based on a “material to form” curriculum around basic equipment such as 3D extrusion pens, clay extruders, 3D scanning devices, software to create or manipulate digital designs, prepare 3D print file while gaining an understanding of parameters that can impact their print quality and print time. These tools are tied with a design thinking process that introduces a novice to a methodological and effective approach to design. The hope is to showcase the applications of this technology as well as to familiarize participants with techniques available to use it for their projects or hobbies. A pilot study was run to observe the effectiveness of the design of the curriculum in communicating the accessibility and simplicity of AM technology for use. Analysis on self-reported survey ratings showed that participants were able to successfully engage with the MAKE 3D as a makerspace, and were able to better understand how to use both 3D printing and 3D scanning tools at their disposal.

Observations on participant engagement level and their involvement at the stations showed us that some stations grabbed more attention compared to others. To address these variations and further expand upon participants’ hands-on experiences, it was determined that a series of revisions were needed to enable more robust participation across the curricular modules and corresponding makerspace stations. First, curricular materials will be extended to include digital copies at computer stations make content more readily accessible. Second, the arrangement of the stations will be deployed in variations that will couple under used and over used stations that test proximity effects. For example, the extrusion station will be deployed in the vicinity of the gallery to find out how the interaction of the modules may effect participation. Last, the research team will develop a schedule of mini demonstrations that will support participants in more technical endeavors while trying to maintain the overall informal context of the makerspace. The next steps for MAKE 3D is to tour four campuses of the Penn State University system along with other possible informal contexts such as the Maker Week at Schlow Centre Region Library in State College, PA. Through the revision process, the research team will remain focused on the fundamental underlying processes and techniques of AM while also maintaining learners' engagement through the informal opportunities of the makerspaces using curricular spectacle.

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7. ACKNOWLEDGEMENTS

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