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The Impact of a Mobile 3D Printing and Making Platform on Student Awareness and Engagement*

SWAPNIL SINHA
Department of Mechanical Engineering, The Pennsylvania State University, 137 Reber Bldg, University Park, PA 16802, USA.
E-mail: swapnilsinha03@gmail.com

KELSEY RIEGER
School of Visual Arts, The Pennsylvania State University, 210 Patterson Bldg, University Park, PA 16802, USA.
E-mail:kzr32@psu.edu

AARON D. KNOCHEL
School of Visual Arts, The Pennsylvania State University, 210 Patterson Bldg, University Park, PA 16802, USA. E-mail: adk176@psu.edu

NICHOLAS A. MEISEL
School of Engineering Design, Technology, and Professional Programs, The Pennsylvania State University, PA 16801, USA.
E-mail: nam20@psu.edu

3D printing technology has played an integral part in the growth of makerspaces, showing potential in enabling the integration of art (A) with science, technology, engineering, and math (STEM) disciplines, giving new possibilities to STEAM implementation. This paper presents the effectiveness of a deployable mobile making platform and its curriculum, focused on 3D printing education. This setup, which draws inspiration from modern makerspaces, was deployed for 227 undergraduate students in Art and Engineering majors at multiple campuses of a large northeastern university and used in either a pre-arranged hour-long session or voluntary walk-in session. Self-reported surveys were created to measure participants' pre- and post-exposure awareness of 3D printing, design, and STEAM quantified through their (1) familiarity, (2) attitude, (3) interest, and (4) self-efficacy. Additionally, observations on participant engagement and use of the space were made. Statistically significant increases in awareness of 3D printing technology were observed in the participants from both Art and Engineering majors, as well as at different campus locations, irrespective of their initial differences. Observations also show a difference in engagement between prearranged sessions and walk-in sessions, which indicates that different session formats may promote specific engagement with different participant types. Ultimately, this research demonstrates two key findings: (1) though they may gravitate to different elements of 3D printing and design, a single makerspace can be used to engage both Art and Engineering students and (2) by introducing mobility to the traditional idea of a makerspace, participants with different initial levels of AM awareness can be brought to similar final awareness. This second finding is especially essential given the disparities in modern student access to 3D printing technology.

Keywords: makerspaces; informal learning; 3D printing outreach; STEAM

1. Introduction

The relatively low-cost nature of desktop 3D printing systems than any other direct manufacturing system has led to rapid adoption, making the technology a key catalyst in the rise of the maker movement. This movement is typified by learning through hands-on design and fabrication experience, which maintains a primacy on sharing, connecting and do-it-yourself tinkering [1, 2]. From an educational perspective, the maker movement has its roots in the theory of constructionism. The theory of constructionism stems from the idea of "learning-by-making," where an individual builds knowledge through active construction of some artifact [3]. The makerspace is one of the most common embodiments of constructionist learning in the maker movement, offering a location where a community of use can form to share knowledge gained through physical construction.

While makerspaces are often comprised of various fabrication technologies, many modern makerspaces incorporate some form of 3D printing technology. 3D printing's relative speed and accessibility 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 3D printing occurs [4]. The 'wow factor' of the printing process often lures users to the various systems [5, 6] and encourages them to experiment with the complex relationships between the 3D printing process and the designs that can be manufactured with it. However, little research is currently dedicated to understanding the impact that such high-visibility 3D printing platforms have on student engagement and learning. This

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work attempts to understand if this curricular '*spectacle*' offered by 3D printing can be leveraged as an effective tool for student-centered education, via a makerspace-inspired environment. To address the opportunities in utilizing makerspaces to promote informal STEAM education, this paper discusses the creation and implementation of the Mobile Atelier for Kinesthetic Education (dubbed *M.A.K.E.3D*), a mobile making platform that capitalizes on the spectacle of 3D printing to promote design and manufacturing learning.

2. Review of Related Work

2.1 STEAM, Makerspaces, and the Role of 3D printing in Education

The interdisciplinary nature of the maker movement allows it to operate organically at the intersection of science, technology, engineering, art, and math (STEAM) disciplines. STEAM initiatives have been found to reinstate the fundamental importance of making to learning, especially evident in digital media skillset development [6, 7]. 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 [8, 9]. Recently, there has been a call from federal legislatures for "*re*integrating the two [STEM and Art disciplines] in our classrooms" [11], but the lack of substantive funding continues to marginalize initiatives in STEAM as a low priority [12]. STEAM has gained momentum as it is taken up in the popular press as a conundrum for educators [13], as a way of merging art and science education [14], and a way to "encourage holistic learning" [15]. 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 [16]. Indeed, research from the NSF-funded "The Art of Science Learning" initiative indicates that student participants benefited from art-based learning via greater collaboration, increased creative thinking, and longer sustained benefits in school and extracurricular participation [17].

At the intersection of STEAM integration and the maker movement lies the constructionist theory of education. Constructionism, an expansion of constructivism [18], posits that learning is at its most effective when students are able to engage with real, manipulable materials and tools toward the creation of a product [3]. Existing literature shows that makerspaces naturally address this educational construct [17, 18]; when participating in makerspace-related activities, students engage with the available materials and tools through direct, hands-on modes of inquiry. This leads participants to establish and expand their knowledge as they explore and interact with the different parts of a makerspace, whether traditional forms of making (e.g., casting) or more modern digitally-supported forms (e.g., 3D printing) Advantageously, constructionism has been shown to support learning in both the sciences as well as the visual arts, though its formal use in the latter is less recognized [21]. By leveraging constructionism, the makerspace in our research was tailored to maximize hands-on inquiry, with specific elements included to naturally on-ramp both STEM and Arts participants. This enables assessment of the way in which such a space affects participants from either end of the STEAM spectrum.

Makerspaces are also perceived to offer a high level of engagement for students within an informal setting. Formal contexts, such as in a traditional classroom setting, may be disconnected from students' everyday lives and not focused on what each student necessarily wants to learn [22]. However, makerspaces are increasingly becoming a part of schools creating more fluid boundaries between formal and informal contexts for education [23]. Makerspaces provide student-centered learning environments that integrate technology and material play, which can encourage more students to find value in school [24]. 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" [25]. Part of what creates this engagement within the makerspace context is the importance of creativity and play with materials that is often expressed through the concept of tinkering [26].

Research on informal learning and makerspaces has demonstrated its import for science education [25–27], and much of this work has focused on libraries and museums [27, 28]. There is also an emerging body of literature that considers the makerspace itself [32].While the specific implementation of modern makerspaces is varied and can include many different technologies (e.g., machining, laser cutting, etc.), such spaces often include 3D printing systems. 3D printing education has been identified as a critical area of research and development in order to encourage widespread adoption of the technology [33]. There have been efforts to explore 3D printing primarily focused on university and industry training [34], but there is also interest in curriculum at the secondary level [35]. It has been found that increasing success of STEM students is connected to creating experiential learning opportunities [36]. Therefore, to grow 3D printing learning, it is crucial to intertwine interdisciplinary curricula with simultaneous hands-on manufacturing experience, for which makerspaces provide a perfect platform [37].

2.2 Existing Forms of 3D Printing "Curricular Spectacle" and Mobile Makerspaces

Research on informal learning and makerspaces has demonstrated its importance for science education [27, 28, 38], and much of this work in informal spaces has focused on libraries and museums [28, 35, 36]. Many of these programs are engaging with issues of maker education in ways that are mobile, open, and accessible to all. The result is what the authors refer to in this paper as "curricular spectacle." By curricular spectacle, we refer to educational efforts that involve highly visible or novel introductions to content or technologies that engage learners immediately while possibly leading to deeper understanding and/or changes in attitude. Attempts in recent years to capture this spectacle-driven fascination with 3D printing technology to informally guide users to a deeper understanding of manufacturing and design include MakerBot Innovation Centers [41] and 3D printing vending machines [42].

Beyond these static forms of informal 3D printing 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 [18, 39–41]. Not only does adding a mobility element to a traditional makerspace increase access to the space and its technology, but it is also supported by the educational theory of situated cognition. Commonly cited in engineering education literature to promote the need for "authenticity" in project-based learning [34, 46, 47] situated cognition suggests that the learning acquired from an activity is inherently intertwined with the context in which the activity was performed [48]. By untethering a makerspace from a fixed location, the social and geographic contexts through which students experience the space can be adjusted to serve the desired learning objectives. This opportunity has led to the rise of mobile making solutions. For example, Stanford's SparkTruck, the educational build mobile, combined a variety of high tech equipment and the mobile platform of a truck to promote hands-on learning [49]. Its success in the maker movement drew attention from educators, and it is now being redesigned by the Southern Methodist University into a teaching tool for K-12 [50]. The STE(A)M truck program by a nonprofit organization Community Guilds, aims to offer "innovation labs on wheels" for students' making focused learning experience. An external evaluation of its students reported statistical significant improvement in their motivation, and intent to persist [51]. All of these making platforms have integrated a variety of technology along with 3D printing to offer a platform for impactful engagement.

While these mobile makerspaces have been shown to excite learning communities and create a sense of wonder regarding 3D printing technology, there have been no studies to assess whether or not users were able to engage and learn from such a spectacle-driven environment. This research therefore explores the shift in participant's awareness towards 3D printing technology and STEAM when exposed to a curricular spectacle in the form of a mobile making platform. Specifically, following on from the earlier discussions of constructionism and situated cognition, this research investigates (1) how participant disciplines affect their awareness of 3D printing and STEAM after engaging with the space as well as (2) how variations in the context of the makerspace (e.g., location, formality of the intervention) likewise affect participant awareness and engagement. The mobile setup (described in detail in Section 3.2) has adaptable curricular stations to engage students with hands-on learning about 3D printing technology. The system will ideally improve informal learning pathways for increasing retention and broadening participation in STEAM for students.

2.3 Research Objectives

The primary research objective of this paper is to explore the effectiveness of a novel, mobile making platform in encouraging participants towards interdisciplinary STEAM fields through 3D printing technology, irrespective of their prior interests and understanding. For this purpose, the following Research Questions (RQs) were explored:

RQ1. Do participants from Art and Engineering majors have differences in their awareness with the topics presented at M.A.K.E.3D before and after their exposure? Additionally, does the way in which they engage with M.A.K.E.3D differ? The curriculum of M.A.K.E.3D is meant to facilitate STEAM learning experiences that employ a range of practices and epistemologies representative of an interdisciplinary approach to hands-on learning, irrespective of the majors of the participants. Even though Art and Engineering majors are fundamentally different in curriculum and learning styles [52], 3D printing technology is expected to generate similar interest and learning in participants from both majors due to the range of play-based and technical making opportunities that the curriculum offers. In this sense, an increase in awareness is an indicator of the effectiveness of a mobile makerspace focused on 3D printing in bridging disciplinary inquiry and offering insight into the attributes of effective interdisciplinary curricula in art and engineering.

RQ2. Do participants from campuses with different student populations have differences in their awareness, before and after their exposure to M.A.K.E.3D? Additionally, does the way in which they engage with M.A.K.E.3D differ? Different campuses may offer different learning environments, due to differences in student populations and educational resources available. Educational resources at academic libraries, and technologically enhanced classroom environments have shown positive impact in promoting engagement in learning [53]. However, student population determines the resources available for each student, which could directly impact learning. Research has shown that attempting to engage a large number of student learners can have a detrimental effect on individual learning due to the limited availability of resources and challenge of achieving personalized engagement [51, 52]. Due to these differences, students from campuses with different student populations may show differences in their awareness of 3D printing before their exposure to M.A.K.E.3D. However, a similar post exposure awareness level is expected between participants as the curriculum has been developed with consideration for different backgrounds and levels of expertise.

RQ3. Do the different types of interaction sessions (prearranged or voluntary walk-ins) for M.A.K.E.3D result in different engagements with the curriculum? The flexibility of the M.A.K.E.3D mobile setup gives an opportunity to study the impact of session type on participant involvement and engagement. Where a walk-in session gives an open-ended timeframe for interaction with the curriculum, a prearranged session for a certain class may limit the time for a group of participants, but ensures a more communal experience. The curriculum is expected to result in similar perceived interest for participants in both session types. However, the limited interaction time in the prearranged timed sessions could lead to differences in engagement levels with the stations.

Note that, while the first two research questions seek to investigate and quantify participant awareness before and after their experience with M.A.K.E.3D, in this study the authors have elected to use the concept of awareness as an umbrella term intended to aggregate a variety of metrics common in engineering design and educational literature. Specifically, awareness within this context encompasses four fundamental components: (1) familiarity, (2) attitude, (3) interest, and (4) self-efficacy. These metrics and their relevance to the M.A.K.E.3D intervention are discussed in more detail in Section 3.3.

3. Presentation

To answer the research questions, the 3D printing-focused mobile making platform, M.A.K.E.3D was developed with an informal learning curricular design. M.A.K.E.3D was then deployed on different campuses of a large northeastern university. Data gathering was performed during deployment of the space, where participants' self-rated surveys were used to study changes in their awareness of 3D printing technology and STEAM concepts. Direct, real-time observation was used to assess participant engagement with the curriculum during the sessions, thus identifying the effectiveness of individual curricular modules. The following sub-sections elaborate on the curricular design (Section 3.1), participants and deployed sessions (Section 3.2), and metrics used to evaluate the effectiveness of the exposure (Section 3.3).

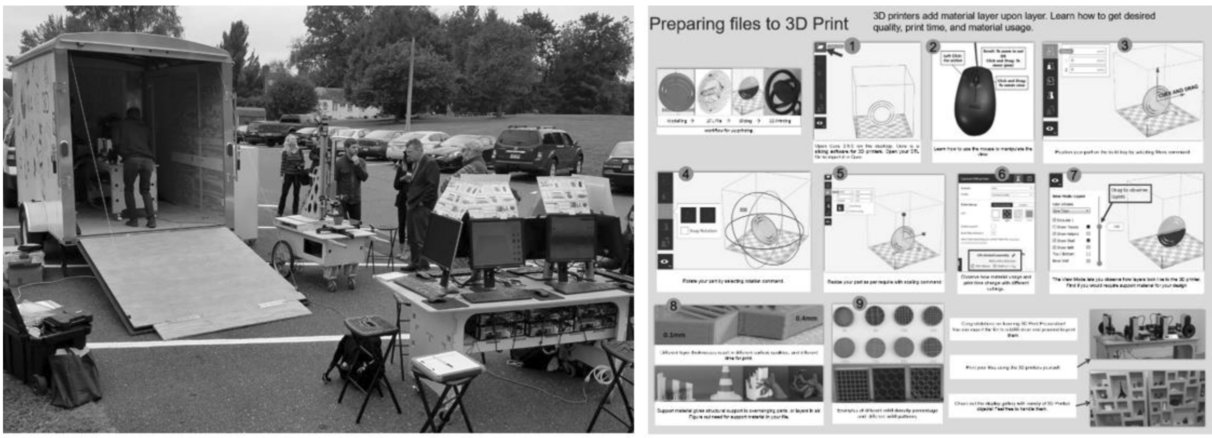
3.1 M.A.K.E.3D Design and its Educational Approach

Just like the mobile libraries which were introduced to provide library services untethered from a single location [56], the mobile aspect of a makerspace increases the physical accessibility of a learning environment. The curriculum for M.A.K.E.3D was developed with the intention of introducing 3D printing in a makerspace-like platform to advance its role in improving STEAM participation. Therefore, the platform was custom-designed accordingly, to cater to these curricular requirements. It is worth noting that traditional makerspaces typically run on membership basis, where the members meet and make as a community. On the other hand, student participation with M.A.K.E.3D is more limited, with participants exposed to the setup only once. In this way, though M.A.K.E.3D is inspired by the constructionism principles that drive the use of makerspaces in education, the actual implementation more closely resembles an educational outreach activity.

The entire deployable M.A.K.E.3D setup is contained within a single mobile trailer. The closed-wall trailer chosen for the implementation (Fig. 1(a)) has an interior space of $132'' \times 72'' \times 78''$. The different equipment, consumables, and support systems necessary to operate M.A.K.E.3D (see Key Materials and equipment in Table 1) were also custom-designed and selected to make use of the limited space and the mobility of the container. When the M.A.K.E.3D trailer arrives at the desired location, all contents can be unloaded and deployed in a flexible configuration. This gives it the unique ability to have the learning space cater to the needs of the student and available space, rather than requiring the student to conform to the limitations of the learning space.

The curriculum for M.A.K.E.3D centers on 3D printing as a fabrication method from an interdisciplinary and introductory-level understanding. Given the nature of M.A.K.E.3D as an informal learning resource for voluntary learners and the project's interdisciplinary platform, the materials and curriculum were made accessible from multiple entry points. Each of the curricular modules was designed to incorporate flexibility to address varying levels of expertise, learning styles, time constraints, and interests. This is done through various demonstrative examples in the form of posters that invite participants to try hands-on activities emphasizing design and inquiry-based methodologies [57]. Based on the application and equipment required, each curricular module can be deployed as an individual station (see Table 1).

Each module was initially developed as self-contained station from start to finish, in order to facilitate a more non-sequential and informal flow of participants (see publication [58] for elaboration on the included curriculum). Additionally, each of these stations contained module-relevant equipment and posters (see Fig. 1(a) and Table 1). These posters demonstrated the use of provided equipment with images, prompting participants to explore the functions themselves. The posters also incorporated directions for some example projects, as well as suggestions to explore other stations to continue or expand the project they have started. For example, at the computer station (see Fig. 2),



(a) (b)

Fig. 1. (a) M.A.K.E.3D trailer deployed in a parking lot. (b) Poster example from the Printer station.

Table 1. Key materials and equipment for stations in the designed curriculum

Stations	Learning Objectives	Key Materials and Equipment
PROTOTYPING STATION for design stages	Participants will explore importance of Design Thinking [59] through creative prototyping activities.	Work space (table and chairs) Card stock Modelling clay
COMPUTER STATION for digital modelling	Participants will gain skillsets for digital modelling through the aid of computers.	Computer workspaces Tinkercad
SCANNING STATION for digital capturing	Participants will understand digital capturing of physical objects with the help of 3D scanners.	Structure sensor Microsoft Kinect Turn-table Computer
PRINTER STATION for work-flow in AM	Participants will understand the process of slicing STL files for 3d print, and the interdependence of design parameters on part quality.	Computer Cura software Multiple 3D Printers (4 Monoprice Minis, and a clay printer)
EXTRUSION STATION for extrusion process & filament variety	Participants will explore the process of extrusion along with the dependence on variety of materials.	3D pens Various Filament materials Scrapped 3D printed parts
GALLERY for showcase and exhibition	Participants will explore various applications of AM with showcased examples, which can motivate them for exploring the technology.	Shelved display galleries Example parts Information cards for displayed parts

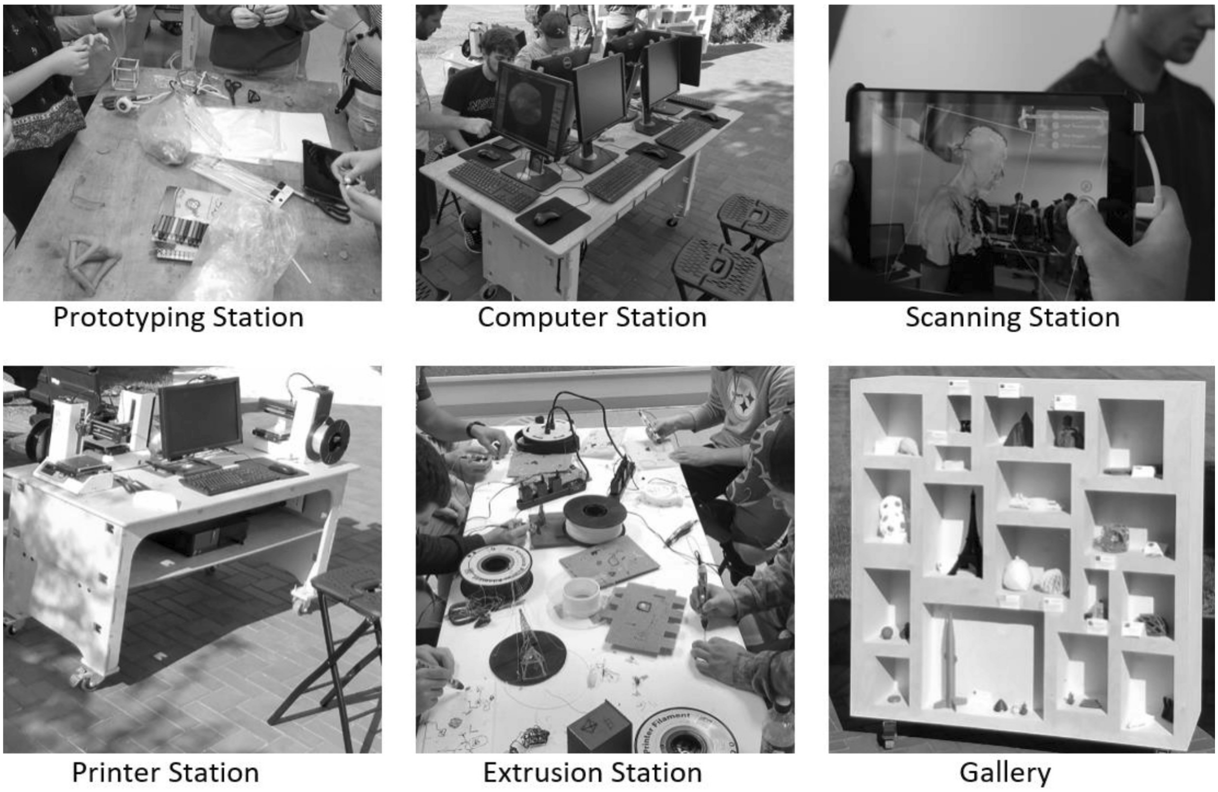


Fig. 2. Example of key components within deployed stations.

the poster (see Fig. 1(b)) demonstrates modelling of a personalized keychain with a gimbal mechanism and encourages users to 3D scan objects to add on to their design as well as to explore the printer station to prepare files for 3D printing.

3.2 Participants and M.A.K.E.3D Deployment Sessions

After a pilot run of the designed curriculum, which showed successful engagement with the student participants [58], M.A.K.E.3D was deployed on five different campuses of a large, research-oriented university in the northeastern United States. Each campus has a different student population. The most populous campus, referred to as Site 1, has an undergraduate population of ~46,000, while the other four campuses are significantly less populous: Site 2 (undergraduate population ~950), Site 3 (undergraduate population ~650), Site 4 (undergraduate population ~4000), and Site 5 (undergraduate population ~600). Sessions occurred during the Summer & Fall semesters of 2017. Where interaction in prearranged sessions was time-limited, the voluntary walk-in sessions did not have such restriction on student participation. These sessions are elaborated below.

3.2.1 Prearranged Sessions

Each of the prearranged sessions took place for an hour, where a freshman-level class of approximately 20 students participated during one of their regular class periods. Before starting their interaction with M.A.K.E.3D, participants were prompted to complete a Likert-scale pre-exposure survey. They were then given a short overview of the premise of M.A.K.E.3D as a mobile making platform before they were allowed to interact with the stations. After approximately 55 minutes of interaction, the participants completed a post-exposure survey identical to the pre-exposure survey. This enables direct comparison to evaluate changes caused due to the exposure.

For deployment at Site 1, a total of seven prearranged sessions were run for freshmen level undergraduate classes of ~20 students, with four session for freshmen-level Engineering students and three sessions of freshmen-level Art students. The participants self-reported themselves as pursuing an Art or Engineering major in the survey. Since the participants were enrolled in entry level courses, their skillsets may not represent professional artists or engineers. Acknowledging this, for consistency of nomenclature, the two groups will be referred to as Art and Engineering majors. These sessions at Site 1 provide a direct comparison between awareness of the Art and Engineering groups before and after being exposed to M.A.K.E.3D. Additionally, four prearranged sessions for Engineering majors were run at the less populous campuses: two sessions at Site 2 and two sessions at Site 3 (see Table 2).

3.2.2 Walk-in Sessions

Contrasting with the prearranged sessions, participants during the walk-in sessions chose to voluntarily engage with the set-up as they passed it. Because of the untimed nature of these sessions (with some as short as 15 minutes and as long as 180 minutes), the participants filled out only one survey to self-report changes in their familiarity, interest, and knowledge at the end of their participation. The walk-in sessions were deployed at the remaining less populous campuses (Site 4 and Site 5), with open access to M.A.K.E.3D lasting for approximately 3 hours. Participant demographics for these walk-in sessions are collected in Table 2.

3.3 Metrics

Research published in 2017 by Peppler and co-authors has shown that present-day makerspaces lack in assessment measuring tools, while they continue to grow in numbers [60]. This could lead to a disconnect in best practice and actual practice due to lack of research [44]. Due to M.A.K.E.3D's novel approach towards the curriculum and exposure, the metrics for measuring effectiveness are not derived from previous publications; rather they were developed by experts in 3D printing, engineering, and visual arts education after evaluating pilot studies run before final deployment of the space [58]. Quantitative and qualitative data was gathered in accordance with a mixed method design that relied on intermethod mixing [61]. Data was collected using (1) self-reporting surveys, (2) observed participant distribution, and (3) observed participant engagement. Each of these are elaborated below.

3.3.1 Self-reported surveys

Participants in *scheduled sessions* were asked to rate a 20 item survey (see Table. 3.) on a 5-point Likert scale, from 'Strongly Disagree' to 'Strongly Agree', immediately before they were introduced to M.A.K.E.3D. This pre-exposure survey consisted of statements intended to evaluate the effectiveness of M.A.K.E.3D outreach. After they completed their 55 minutes of interaction with M.A.K.E.3D, participants completed the same survey again, to collect insight on their awareness of 3D printing and STEAM post-exposure. Both the pre-survey and post-survey measured four components of a participant's awareness: '*familiarity*', '*attitude*', '*interest*', and '*self-efficacy*'. The purpose of four different components of the survey are elaborated below:

Familiarity: These statements aimed to measure participants' most basic understanding of the topics or the factual knowledge that captures their comfort with the topics.

Attitude: This component of the survey captures a participant's belief that these topics are useful in their education or work. The aim is to understand how participants change their relatability to M.A.K.E.3D. High relatability ultimately leads to improved self-efficacy and positively impacts student retention in STEM, as shown in previous studies [62, 63])

Interest: This component of the survey captures participants' curiosity in the topics presented through M.A.K.E.3D. The previous two components capture parts of knowledge and attitude towards the topics that may not capture if they have curiosity in the topics presented [64]. For example, participants with no knowledge on the technology will report a neutral attitude towards it. The interest component for these participants would then quantify their curiosity in the topic, essential for determining their openness to learning about it.

Self-Efficacy: The survey also intended to serve as a student self-assessment tool by focusing their attention to specific topics for improved learning [65]. Self-efficacy questions in the survey aimed to evaluate change in self-perceived estimation of participants' knowledge in 3D printing and STEAM. Self-efficacy is often found to correlate with confidence [66], and retention in science and engineering [62]. Measuring self-efficacy is therefore an important estimate of M.A.K.E.3D's effectiveness for education.

Table 3 presents the survey questions for the M.A.K.E.3D outreach activity and categorizes

Table 2. Demographics of the participants from different sites, with respect to their majors

Location	Session Type	Major	Total no. of Participants	Frequency of gender in each group			Frequency of ages of the participants in each group			
				Males	Females	Others	18	19	20	21+
Site 1	*Prearranged*	*ART*	46	13	32	0	31	10	2	1
Site 1	*Prearranged*	*ENGINEERING*	72	61	11	0	64	7	1	0
Site 2 & Site 3	*Prearranged*	*ENGINEERING*	80	69	9	2	36	23	5	11
Site 4 & Site 5	*Walk-in*	*MIXED*	29	16	13	0	7	3	7	9

Table 3. Reliability (Chronbach's α) of the components of awareness reported through survey, for analyzing M.A.K.E.3D effectiveness

Components to evaluate effectiveness of M.A.K.E.3D exposure		PRE (α)	POST (α)
Familiarity			
1	I am familiar with concepts of makerspace	0.604	0.599
2	I understand the concepts of 3D printing		
3	I am familiar with the concepts of design thinking		
4	I understand how individuals working in STEAM work together in design and making processes		
Self-efficacy			
5	I know how to 3D print	0.78	0.727
6	I can 3D model objects on a computer		
7	I know how to 3D scan objects		
Interest			
8	I am interested in going to a makerspace	0.554	0.714
9	I have interest in working in STEM fields		
10	I have interest in working with collaborators from STEM fields		
11	I have interest in working in art and design fields		
12	I have interest in working with collaborators from art and design fields		
13	I am interested in forms of transdisciplinarity that involve art and STEM related fields		
Attitude			
14	3D printing is important to the future	0.776	0.859
15	I believe that using a makerspace could improve my education		
16	I see the potential of using designing/ modeling objects on a computer for my work		
17	I see the potential of using 3D scanners in my work		
18	I see the potential of using design thinking in my work		
19	I see the potential of using iterative design process in my work		
20	I see the potential of prototyping in my work		

them according to the component of awareness they represent. The table also includes measures of the tool's reliability by way of Chronbach's α for each component, via pre- and post-survey ratings by the participants.

As previously discussed, participants in the walk-in session were asked to fill out only a post-exposure survey, which was modified to capture their self-rated *change* in awareness for the same components. To capture this change, each survey element from Table 2 was reworded as follows:

"After visiting MAKE3D,

I have *increased* familiarity with concepts of makerspaces.

I *better* understand concepts of 3D printing. . ." and so on.

3.3.2 *Observed Participant Distribution and Engagement*

While there is a range of established observation protocols that focus on active learning in engineering education settings [67], the M.A.K.E.3D setup provided a unique learning space that was active and self-guided; as such, instructor-focused protocols would not capture the desired student interaction with the space. Therefore, a design-based research approach [68] was taken to develop a protocol that was prototyped and progressively focused through successive piloting in the summer of 2017 [58].

To capture the engagement during their time with M.A.K.E.3D, participant distribution, and their interaction level were recorded for each station every 10 minutes by two observers. For participant distribution, observers recorded the number of participants that were interacting with each station at the time. Simultaneously, the observers rated participant engagement on a five-point scale, as shown in Table 4, based on the level of participation. As an example, observers would collectively rate the participants' engagement 1, if they were only looking or observing a station. They would rate higher on the basis of participants' inquisition, equipment usage, peer interaction [69, 70], and on/off topic discussions. Each observer recorded these values by collectively rating the group of students on a station, at the same timestamp. For analysis, the ratings from the two observers for a given time

Table 4. Engagement scale for qualitative observation for interaction

Ratings	Scale
1	Looking & observing
2	Asking questions
3	Using materials
4	Using materials with purpose
5	Added use of curricular materials

stamp were averaged individually for each station. Qualitative data also included the extent to which participants were engaging with the M.A.K.E.3D facilitators. Specifically, observers noted if there was an active demonstration by facilitators, if facilitators were present and interacting with participants at a station, or if participants were at a station without the presence of a facilitator.

4. Results

The results of data analysis are reported below, after removing missing data sets and replacing 0.2% of the unavailable data with means. As discussed in Section 3.2, for prearranged sessions, participants completed both the pre- and post-exposure surveys. To analyze the effectiveness of M.A.K.E.3D for these sessions, the responses for pre- and post-exposure surveys were statistically compared for within subject differences with a paired sample t-test. To analyze the differences in the groups being compared in the research questions, the differences in responses for the components (familiarity, attitude, interest, and self-efficacy) were analyzed between the groups with an independent sample t-test. The value for each component of awareness was obtained by averaging the ratings of all corresponding statements in the survey. The data was further analyzed to determine if a participant's background impacted their awareness before and after interacting with M.A.K.E.3D. For walk-in sessions, participants completed only a post-exposure survey designed to identify their self-reported changes in awareness due to M.A.K.E.3D exposure.

For the analysis of the observational data on the number of participants and engagement ratings at each station, the average from the two observers at a given time stamp was used in addition to field notes that were recorded in the timed intervals as well. Independent sample t-tests were used for statistical comparison of the number of participants and engagement ratings between the groups.

RQ1. Effect of Art and Engineering Majors on Perceived Awareness, Before and After Exposure. A total of seven prearranged sessions were conducted with four undergraduate classes from Engineering and three from Art participating at Site 1 (Table 2). All the assumptions for the relevant statistical tests were verified. Both groups showed a significant increase in awareness for all relevant statements in each component, shown in Fig. 3. ($p < 0.0001$). It is essential to also understand how the two majors collectively differed in their pre- and post-exposure awareness as perceived by the participants themselves. This allows for better understanding of the impact that their backgrounds have on their experience.

Pre-exposure survey analysis showed that prior to the sessions, the two majors significantly differed in their responses for all components ($p < 0.0001$), with larger differences in the components of attitude (mean difference 0.512) and self-efficacy (mean difference 0.61). Further analysis show that Art major participants rated themselves lower than Engineering major participants in their attitude towards the potential of using computer modelling, 3D scanners, iterative design, and prototyping in their work. Furthermore, Art majors showed an overall lower score in self-efficacy towards 3D printing, 3D modelling, and 3D scanning. As expected, observations in the interest component show that Art participants showed a higher interest in working and collaborating with art and design fields, where Engineering participants showed a higher interest in working and collaborating with STEM fields. Both majors reported a similar interest in going to makerspaces and interest in STEAM. There were also no significant differences in familiarity with design stages or 3D printing concepts, where both majors reported a "neutral" to "agreeing" score.

Post-exposure survey analysis showed that attitude, interest, and self-efficacy still had small but statistically significant differences between the groups ($p < 0.0001$). Overall, both majors showed an improved awareness in their post-exposure survey; however, there were still significant differences between the majors. Specifically, Engineering participants improved from "neutral" to "agreeing" towards interest in working in art and design fields, while Art major participants improved from "disagreeing" to "neutral" for interest in working with STEM fields. This indicates that participants' background did have a partial influence on their awareness before and after the exposure to M.A.K.E.3D. However, both majors had similar levels of familiarity ($p > 0.076$) after participation, which demonstrates the effectiveness of M.A.K.E.3D.

Qualitative observations were performed for each station by two raters with a high inter-rater reliability (Cronbach's Alpha value of 0.761). The number of participants at each station was recorded

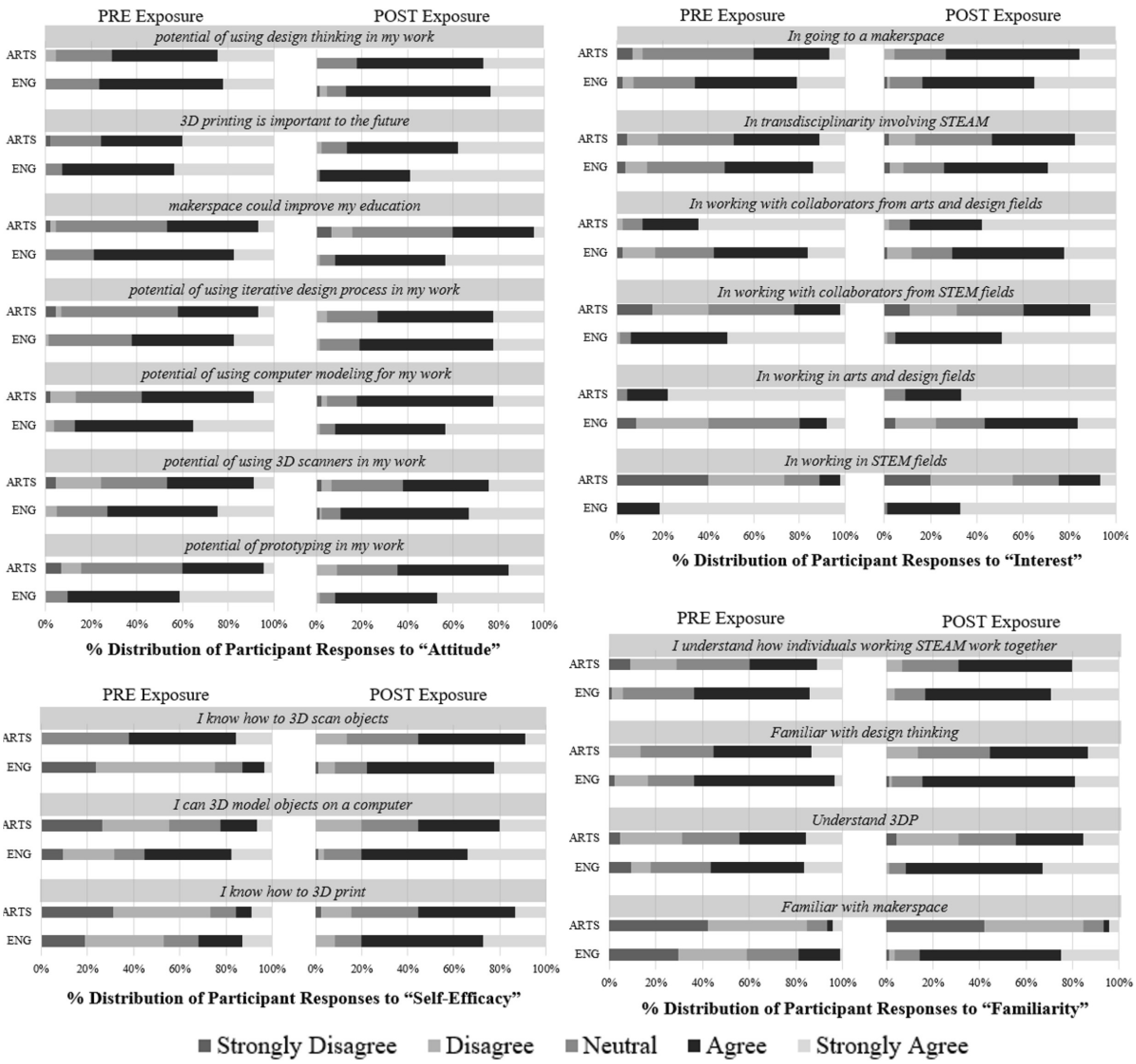


Fig. 3. Ratings pre- and post-exposure for each component of the survey, by *Engineering* and *Art* major participants at site 1.

every 10 minutes along with their engagement with each station and research facilitators. Analysis shows slight differences in distribution of the participants among the stations (Fig. 4). Where more participants from Engineering were exploring the Extrusion station compared to Art participants, more participants were involved in the design and scanning sessions for the Art major. Rated engagement levels showed a significantly higher engagement for the Engineering major participants at all the stations, with the largest differences observed when exploring the gallery and using the 3D printing station (Fig. 4). Observation data show the relative involvement of research facilitators in the instruction of the 3D printing station as opposed to those stations that were open for inquiry like the extrusion and design stations. Stations such as computers and scanning required at a minimum an introduction and oftentimes a demonstration of the equipment and procedures. Therefore, increased participation at the extrusion station by Engineering participants and the design station by the Art participants both align with more open-ended making opportunities, but with a much different array of tools and materials possibly indicating disciplinary alignments.

RQ2. Effect of campuses with different student populations on perceived awareness, before and after exposure?

To evaluate the effect of campus population when using M.A.K.E.3D, survey responses from Site 1's prearranged sessions for the Engineering major (discussed in results for RQ1) were compared with the responses of similar sessions obtained from two less populous campuses (Site 2 and Site 3).

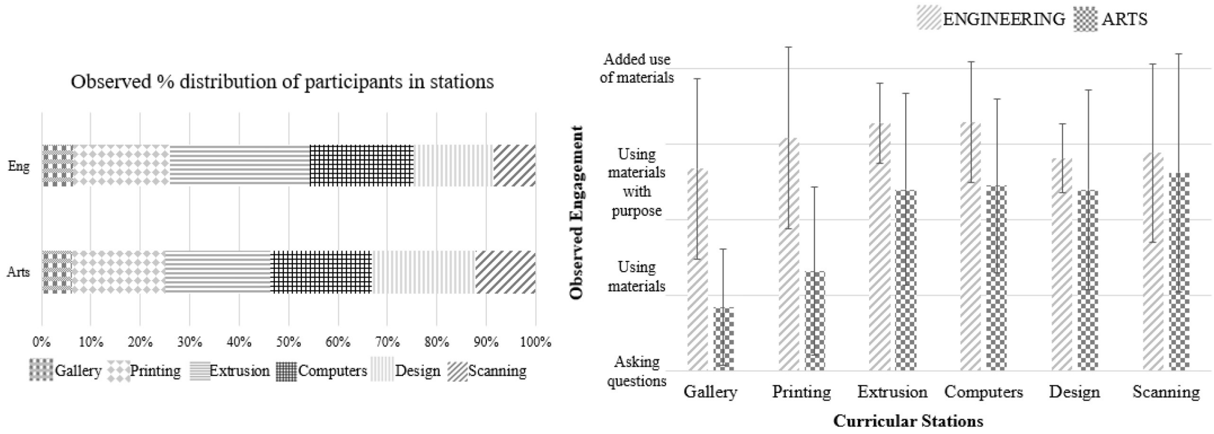


Fig. 4. Averaged percent distribution of participants at each station, and average engagement levels of participants as observed at each station (with standard deviations as error bars), for *Engineering* and *Art* majors.

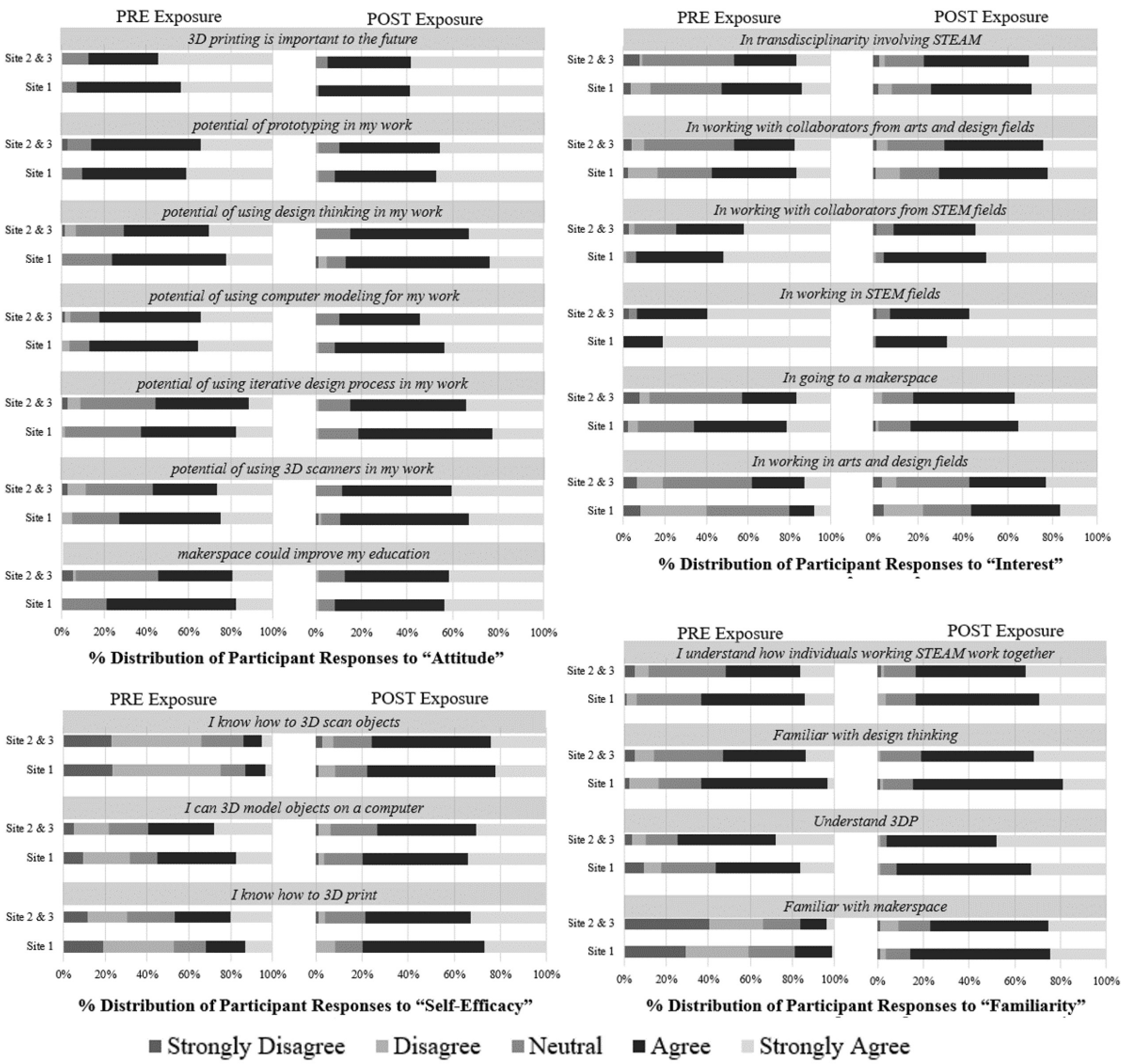


Fig. 5. Ratings for pre- and post-exposure awareness compared for participants from *Engineering* majors for Site 1 and for Sites 2 & 3.

On comparing pre- and post-exposure responses, both the groups showed significant improvement in all components of awareness ($p < 0.0001$). However, there was no significant difference between the different campus sites used in this study; participant at all sites showed similar overall responses for all components of awareness ($p > 0.10$).

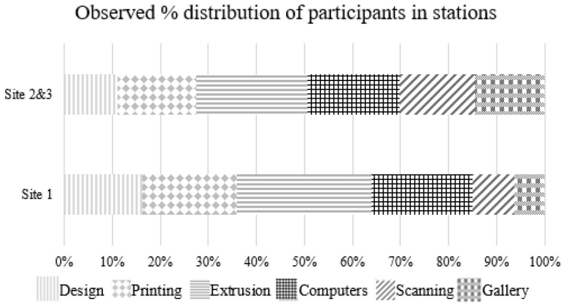
Further observation of awareness scores in the pre-exposure survey shows that, while most statements rated similarly, there were several individual statements with significant differences between sites. For example, Site 2 and Site 3 participants reported an overall higher awareness for understanding concepts of 3D printing ($p < 0.027$) and knowing how to use 3D printing ($p < 0.031$), than participants at Site 1 (mean difference of ~0.40). Conversely, participants from Site 1 rated themselves higher in their interest in going to makerspaces (mean difference of 0.40) and their interest in working with collaborators from STEM fields (mean difference of 0.35). Less populous campus participants rated higher agreements for interest in the design and art fields (mean difference of 0.50). Ultimately, after exposure to M.A.K.E.3D, participants from all sites rated similarly for each statement ($p > 0.23$), which indicates that participating in this outreach activity can achieve relative parity between participants, regardless of which campus they originate from.

Observation of participant distribution during the activity showed that Site 1 participants congregated at the 3D printing, Extrusion, Design, and Computer stations, where participants from less populous campuses were drawn towards the Gallery and Scanning stations (Fig. 6). The engagement levels were likewise higher for Site 1 at the Extrusion, Design, and 3D printing stations, while other stations saw similar engagement levels between all three campuses (Fig. 6). Observation data indicates that some of these differences can be attributed to how the participants chose to interact with research facilitators. For example, Sites 2 and 3 do show more frequent interaction with the Gallery, but this higher level also corresponds to more interaction at the station between participants and research facilitators. Another example is the scanning station; early interaction with facilitators at this station at Site 2 created an environment where several student participants became unofficial station "experts" for their peers. These students then acted as facilitators themselves to their peers at that station, increasing overall use of the station. The impact of these forms of interaction between facilitators and participants suggests that students at Sites 2 and 3 chose to leverage their newfound access to the human resources in the space (i.e., the facilitators) as much as they did the physical resources. Conversely, participants at Site 1 more commonly frequented stations that could be considered self-driven. As Site 1 is the home campus for the research team members and other faculty with 3D printing expertise, participants may not have felt the need to take advantage of M.A.K.E.3D's human resources and selected a station accordingly.

RQ3. Effect of Session Type on Perceived Interest and Engagement with the Curriculum

For the voluntary walk-in participation, individuals interested in the deployed M.A.K.E.3D enquired about the setup and started interacting. As reported in the "Metrics" section, only a post-survey, specifically designed to identify self-reported changes in awareness, was completed by 29 participants at Site 4 and Site 5. Therefore, the obtained survey data cannot be directly compared with the pre- and post-exposure survey data from prearranged sessions.

The responses for each component of awareness were checked for their reliability through Chronbach's α (familiarity (α = 0.798), attitude (α = 0.918), interest (α = 0.877), and self-efficacy (α = 0.880)). Analysis shows that all participants reported an "agreeing" attitude for the statements, indicating a positive experience (see Fig. 7.). It is important to note that the duration of participation



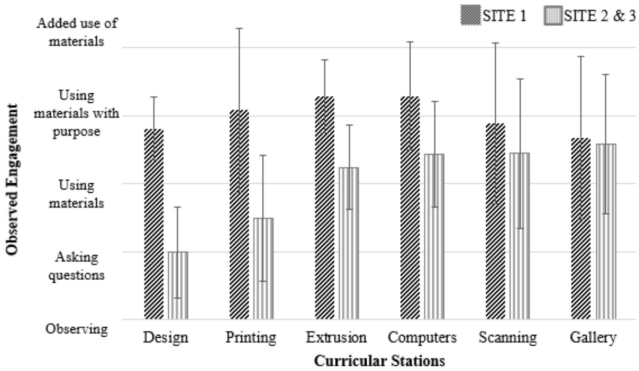


Fig. 6. Average participant distribution at each station, and average observed engagement levels of the participants (with standard deviations) for each station as observed by the raters in *prearranged* sessions at a populous (Site 1) and less populous campuses (Site 2 & 3).

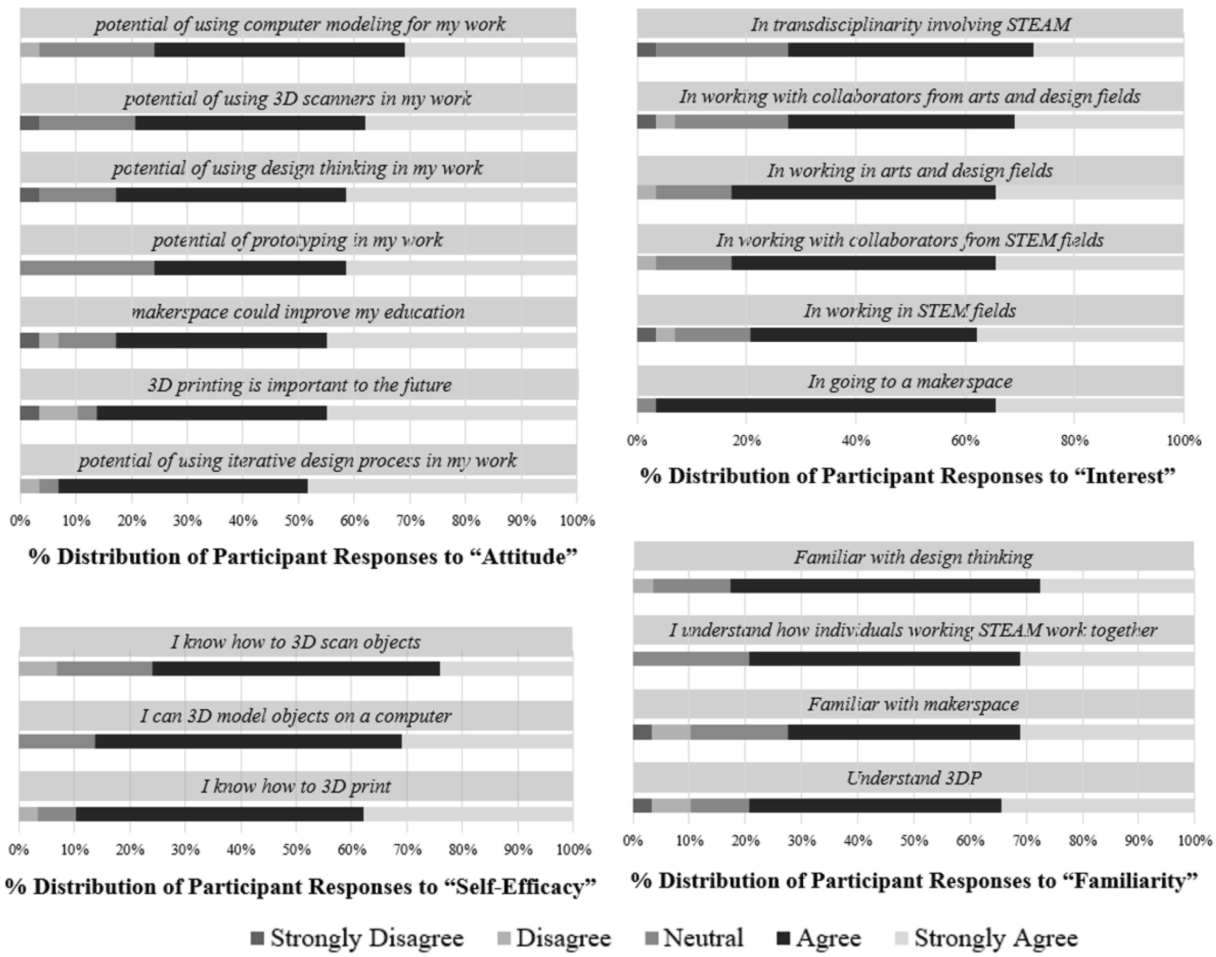


Fig. 7. Responses with standard deviations, by 29 walk-in participants for each of the components.

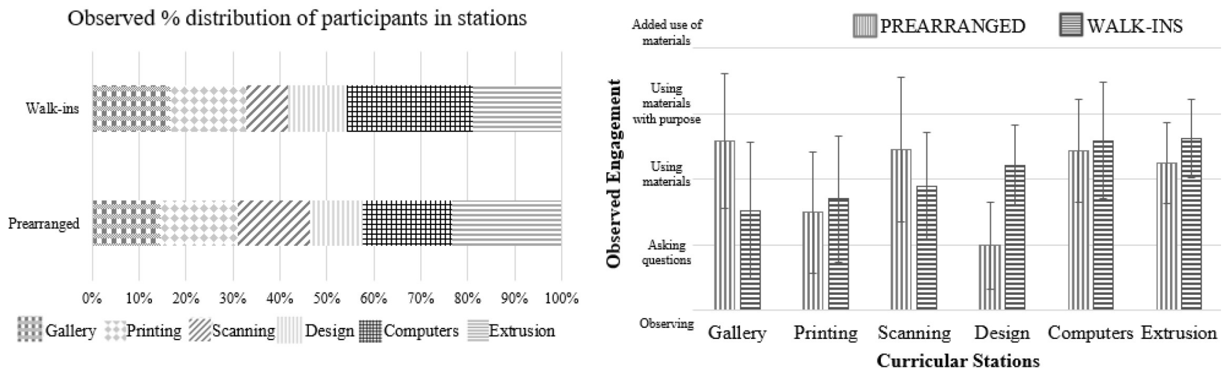


Fig. 8. Average participant distribution at stations in prearranged and walk-in sessions, and average observed engagement levels,with standard deviations as error bars, for participants at each station, in prearranged and walk-in sessions.

for the participants who filled out the survey ranged from fifteen minutes to three hours, with the average interaction lasting for approximately an hour.

Data collected through observation was compared with prearranged deployments at Site 2 and Site 3, to gauge the difference in overall engagement and involvement between the two session types at campuses with similar populations (Fig. 8). It was observed that a higher number of participants interacted with the Computer station during walk-in sessions (27%), than in prearranged sessions (19%). Alternatively, the Scanning and Extrusion stations attracted more participants in prearranged sessions than in walk-ins. Higher engagement levels were observed in the walk-in sessions at the Computer, Design, and Extrusion stations, where prearranged sessions showed higher student engagement at the Gallery and Scanning stations (Fig. 8).

5. Discussion

Overall, the analysis shows that participants reported improvement in all components of awareness reported through their pre- and post-exposure surveys. This indicates that M.A.K.E.3D was effective in improving familiarity, attitude, interest, and self-efficacy for the topics it presented. Improved interest from each discipline (art and engineering) in collaborating with the other (e.g., art with engineering, engineering with art) also implies that 3D printing is an effective tool for integrating the art and STEM fields. The differences in reported engagement can be reasoned with differences in prior knowledge of 3D printing-related technology. Students in the Engineering major not only reported higher agreement for familiarity and self-efficacy with 3D printing, 3D scanning, and 3D modeling than students in the Art major, but also showed higher engagement when using these stations. The difference in participant distribution within stations between the two majors indicates the success of the informal curriculum setup in letting individuals tailor the curriculum for themselves. This could have caused the observed engagements and increases in awareness for both majors, as they followed their instincts due to their genuine curiosity when engaging with the stations. This suggests that, when attempting to use makerspaces to engage students from across STEAM, educators must consider the inclusion of both freeform, open-ended content (such as the extrusion and design stations) as well as more technical, procedural content (such as the 3D printing station). In doing so, it is possible to significantly improve the components of awareness for students from both the Engineering and Arts fields.

On comparing the data for pre-arranged sessions at populous (Site 1) and less populous (Site 2 and Site 3) campuses, pre-exposure awareness scores were found to be different for both groups of participants. Interestingly, participants from less populous campuses showed better agreement in conceptual understanding of the 3D printing technology than Site 1 participants. Site 1, being the largest campus in the university's system, has an undergraduate population of approximately 46,000 students, compared to 950 students in Site 2 and 650 students in Site 3. The higher number of students per printer at Site 1 could explain the lower rated conceptual understanding of 3D printing technology when compared with the less populous campuses. Even though the less populous campuses have fewer 3D printing systems, their lower student populations may enable more frequent or in-depth interactions with these systems, which could be the reason for participants from less populous campuses reporting better initial conceptual understanding of the technology. After exposure to M.A.K.E.3D, both groups ended with similar awareness levels, which signifies successful and effective deployment of the curriculum, irrespective of the campus location of the participants.

On comparing the scheduled and the voluntary walk-in sessions through observational data, higher involvement with the computer station in the walk-in sessions were observed, and could be caused by the flexibility offered in walk-in session, which allowed participants to gravitate toward the relatively familiar computer interface used for 3D modelling. The computer station also offered a comparatively wider range of projects, such as creating new, novel geometry using the provided software or importing previously existing models or 3D scanned data. In contrast, participants in the scheduled sessions spread out more evenly, potentially due to limited time and limited seating at the various stations for exploration of all the available resources. The freedom in time for involvement with the walk-in sessions could have caused this difference in distribution, and as a result, in engagement. As educational institutions grow their makerspace offerings, this finding shows the importance of including familiar entry points for student engagement, such as the previously discussed computer station. This will enable participants to gain comfort with the space and ideally encourage them to then further explore the more unfamiliar offerings available within the space.

6. Conclusion

As evident from the analysis, the informal and introductory-level setup of M.A.K.E.3D curriculum was successful in improving awareness in 3D printing topics with a wide range of participants in both the Engineering and Art fields and at a variety of deployment locations. There were significant differences for all components of awareness when comparing Engineering and Art majors prior to exposure to M.A.K.E.3D. However, the post-survey showed that participants from both majors were able to significantly improve their awareness. Campus population had an effect on pre-exposure awareness in the participants. Post exposure, all the participants ended with similar awareness levels. This reinforces the usefulness of M.A.K.E.3D's mobile nature as well as its ability to adapt to different geographic and student contexts, while still leading to increases in participant awareness of 3D printing and design concepts. This further lends credence to the rise in mobile making solutions across education, as detailed in the review of literation in Section 2.2. Further evidence of the mobile making platform's flexibility was explored by analyzing the post-survey data for walk-in sessions. Overall, positive self-rated responses from the participants indicated an effective reception of the curriculum. An increased enthusiasm for STEAM also indicates the effectiveness of 3D printing technology in encouraging interdisciplinary learning. Furthermore, the mobile set-up of M.A.K.E.3D was able to deploy effectively in locations not typical of a makerspace, with no reported negative impacts on participant experiences. The set-up also proved efficient in various types of sessions, either pre-arranged for an existing class or as voluntary walk-in activity. However, differences in involvement were observed for these different sessions, which could be caused by participant preferences and existing familiarity with the technology.

Further studies are required to better understand the flow and sequencing of participants through M.A.K.E.3D as a group or individually. To achieve this, a method to track individual participant interaction with the space is first needed, which can then be used to understand the link between a participant's prior knowledge and their self-tailoring of the experience. Investigating the individual experience can also be supported through the collection of additional qualitative data following participant use of the space. Such collection could occur through semi-structured interviews. This understanding can then inform an approach to design informal curriculum for similar setups. Retention of the knowledge provided by the M.A.K.E.3D must also be quantified to evaluate the space's effectiveness in broadening participation in STEAM fields. Furthermore, different setups with different station locations could be explored to further improve the curricular spectacle offered by the presented setup. This study demonstrated that the informal curricular setup of the mobile making platform for 3D printing was effective in engaging participants from different levels of experience and positively impact their awareness toward 3D printing and STEAM learning. Similar curricular setups are therefore encouraged to reinforce prior knowledge, expand participation, and provide an adaptable learning space for 3D printing technologies.

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Swapnil Sinha is a PhD candidate in Mechanical Engineering department at Penn State. Her research is focused on impact of design decisions on material properties, for creating quality multifunctional products through Additive Manufacturing. Swapnil holds a Master of Science degree in Engineering Design from Penn State, and B. Tech in Mechanical Engineering from Manipal Institute of Technology, India.

Kelsey Rieger is a graduate student at Penn State University. Her professional background is in museums and community arts engagement, and she is currently pursuing her Master's degree in art education. In addition to her participation with M.A.K.E. 3D, her work engages with multidisciplinary, place-based, and creative programming solutions for informal learning environments

Aaron D. Knochel, PhD, is Associate Professor of Art Education in the Penn State School of Visual Arts and an Embedded Researcher at the Art & Design Research Incubator (ADRI) at The Pennsylvania State University. Dr. Knochel's research focuses on intersections between art education, transdisciplinarity, and media studies. Publications include articles in *Studies in Art Education, Visual Arts Research*, *The International Journal of Education through Art*, and *Kairos*. Generally, he tries to live up to his @artisteducator twitter bio: artist-teacher-visual culture researcher-digital media flaneur-novice hacker and pixel stacker. See https://sova.psu.edu/profile/aaronknochel

Nicholas A. Meisel, PhD, is an Assistant Professor of Engineering Design in the School of Engineering Design, Technology, and Professional Programs (SEDTAPP) at Penn State and an affiliate faculty in the Department of Mechanical Engineering. He graduated from Virginia Commonwealth University in 2010 with his B.S. in Mechanical Engineering and received his Ph.D. from Virginia Tech in Mechanical Engineering in 2015. He is the director of the Made By Design Lab, which seeks to understand how Additive Manufacturing (or 3D Printing) is changing design complexity, design guidelines, and design thinking in engineering.