

**A STUDY OF STUDENTS' TOOL USAGE AND INVOLVEMENT
WITHIN ACADEMIC MAKERSPACES**

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A STUDY OF STUDENTS' TOOL USAGE AND INVOLVEMENT WITHIN ACADEMIC MAKERSPACES

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LIST OF SYMBOLS AND ABBREVIATIONS

CAD Computer Engineering Design

EDM Electric Discharge Machine

EE Electrical Engineering

ME Mechanical Engineering

URM Underrepresented Minority

SUMMARY

Over the past two decades, many studies have analyzed the extensive benefits of makerspaces towards student education, design-self efficacy, and community involvement. However, less work has been dedicated to examining the ways in which students interact within makerspaces. This study seeks to dive deeper into the patterns of tools that students are using and how this knowledge can inform makerspaces and make them more effective. Tool usage data was collected through end of semester surveys administered to students at two large public universities over the course of 5 semesters: Fall 2020, Spring 2021, Spring 2022, Fall 2022, and Spring 2023. The survey asked a variety of questions about prior makerspace experience, general and specific tool usage, and student demographics. The first three semesters of data were used to gain an understanding of how different student groups – defined based on categories such as major, demographic, or class taken – interact with various tools within the space. Combined semester analysis was used to understand how underrepresented minorities were utilizing the space while between semester analysis was used to see trends in makerspace usage over time. The onset of the COVID-19 pandemic at the start of the study provided ample opportunity to examine the effects of unprecedented disruptive events and the resulting restrictions on the health of makerspaces and student interactions. Results showed substantial differences in usage between schools and student groups as well as a decline in usage following the onset of COVID restrictions. In the final two semesters, a pilot study was conducted at both makerspaces to determine how hands-on, and tour-based workshops offered to students can be used to increase tool usage in makerspaces and more successfully welcome new students into the maker world.

While there is insufficient data to make any conclusions from these interventions, they showed the potential for promising results if future work is performed. Finally, insights from this study are used to offer suggestions to makerspace administrators on how to address poor makerspace usage.

CHAPTER 1. INTRODUCTION

1.1 Context and Motivation

Over the past two decades, the words “maker” and “makerspace” have become increasingly common in English vocabulary. Dale Dougherty, the man credited with popularizing the maker movement, explains that few people call themselves inventors, but many identify themselves as makers in some sense [1]. Making encapsulates a myriad of activities including hardware, software, textiles, and even cooking. Makerspaces exist as collaborative workspaces where people of diverse backgrounds, but similar interests gather to work on projects and share ideas, skills, and equipment. They may house a wide array of tools including 3D printers, laser cutters, wood and metal working machinery, computers, electronics, and craft equipment. Today, makerspaces can be found many different places including K-12 schools, museums, libraries, community centers, and college campuses [2].

Prior study of academic makerspaces has shown that they are a tremendous asset to engineering curriculum and offer many positive benefits such as increased design self-efficacy [3-6], motivation [3, 7, 8], innovation [7, 9], and communication [7, 8] to the students who use them. Given all these affordances, it is critical that makerspace staff invest in studying their makerspaces to keep them as welcoming and effective as possible. The purpose of this study is to understand how students are interacting with tools within makerspaces, what factors hinder makerspace use, and how makerspaces can best be prepared for future obstacles.

Previously, makerspaces have most often been studied through sign-in systems [10-12], interviews [11, 13, 14], and surveys [10, 12, 13, 15]. While these methods provide knowledge about user demographics, motivations, and tool usage, they fail to provide comparable quantitative metrics of health. The survey analysis presented here was conducted as part of a larger study in which the makerspaces were modelled as bipartite networks, inspired by mutualistic networks studied in ecology. Metrics of modularity, nestedness, and connectance were used to evaluate and quantify makerspace health and understand its underlying structure [16-19]. The results of the network analysis are not included in this thesis, but the survey analysis presented is primarily being used to support the validity and usefulness of this novel method [20-22].

1.2 Research Objectives and Thesis Structure

Three different but connected sets of analysis are presented in this thesis. The objectives and driving questions associated with each are described in the subsequent sections.

1.2.1 Understanding Usage Patterns

Despite all the benefits shown for students who use academic makerspaces, not all students use them equally [23-25]. Chapter 4 examines the combined data collected over five semesters to compare usage between two schools and between different groups of students, organized by factors such as gender or major. Understanding these dynamics allows makerspace staff to recognize usage discrepancies and seek to make their spaces as diverse and welcoming as possible. Two research questions are addressed:

RQ 1.1) How are making patterns different between School A and School B (the two schools studied)?

RQ 1.2) How are making patterns different between groups of students at these schools?

1.2.2 Understanding the Effect of Disruptions and Restrictions

When growing numbers of COVID-19 cases threatened the United States in early 2020, college campuses closed their doors and university makerspaces were shut down [26]. When colleges slowly opened back up, makerspaces experienced immense restrictions, changing the way they were operated and used by students [27, 28]. This provided a unique opportunity to study how makerspaces handle disruptions and gave insight into identifying and reacting to future disturbances. This analysis, presented in Chapter 5, was performed by examining tool usage across three Spring semesters spanning during and after the COVID pandemic. Two research questions are addressed in this section:

RQ 2.1) How are academic makerspaces and student usage patterns affected by large scale disruptions?

RQ 2.2) What can makerspaces do to address poor makerspace health, especially when caused by external disruptions?

1.2.3 Understanding How to Engage New Makers

Finally, a pilot study is presented which seeks to understand why students are not using makerspaces equally and how underrepresented groups can best be engaged. A series of hands-on and tour-based workshops are implemented as methods to get students involved and interested. This study seeks to answer the following questions:

RQ 3.1) How do students perceive their sense of belonging in the makerspace?

RQ 3.2) How is sense of belonging correlated with factors such as gender, major, study habits, and classes taken?

RQ 3.3) Are workshops an effective method of engaging new students?

RQ 3.4) Are hands-on workshops or tour workshops more effective?

CHAPTER 2. BACKGROUND

2.1 The Maker Movement in Education

People have been making things since the beginning of time. As such, it is difficult to define the exact start of the maker movement. It is clear, however, that physical hubs for making have become increasingly popular in recent years [29]. *Makerspaces*, *Hackerspaces*, and *FabLabs* are all newly developed words used to define these places. Hackerspaces were born as a result of the open-source software community and typically describe places where computer enthusiasts can come together to work on technology related projects and problems [30]. The first University makerspace was created at MIT in the early 2000s [31] and was followed by the formation of the Fab Foundation, which offers specific instructions and support for creating structured spaces known as FabLabs [30, 32]. The term Makerspace originated with Dale Dougherty's creation of Make Magazine and Maker Faires [1, 30, 32]. Today, the term is open ended and is often used to encapsulate any sort of similar spaces used for collaborative making of any type. This is the way the term will be used throughout this thesis.

Many factors, often unrecognized, have contributed to the recent rise in makerspaces. National emphasis has been placed on seeking progressive education pedagogies and rewarding innovative teachers [30, 32]. Additionally, knowledge sharing platforms such as Github, Instructables, and Make Magazine have made sharing ideas and instructions far easier than ever before [2, 30]. Similarly, fabrication equipment has decreased substantially in price, allowing companies, schools, libraries, and individuals more access to this type of equipment [30]. What began as a grassroots community based movement is now prevalent

in more formal applications including K-12 schools and universities [32]. While many college campuses already contained the individual elements of a makerspace – machine shops, collaborative workspaces, testing labs, etc. –they are now combining those elements into cohesive makerspaces [33].

University makerspaces are as diverse in design and functionality as the campuses that contain them [31, 33, 34]. A survey of 40 university makerspaces revealed that there is certainly no “one size fits all” model [31]. These spaces vary in location, membership, equipment, and staffing structure to best meet the specific needs of each campus and each student body [31, 34]. Makerspaces may be located on or off campus and may serve engineering students, general campus populations, or even the outside community [31, 33, 34]. Some are faculty run, some are student run, some are special staff run, and many implement a mix of these staffing structures [31, 33].

2.2 Benefits of Academic Makerspaces

A variety of empirical studies have shown that makerspaces provide immense benefits to the students who use them by giving the students the opportunity to learn both by doing and through others [35]. This produces and strengthens cognitive, intrapersonal, and interpersonal skills [35]. A five-year longitudinal study conducted at three US university makerspaces found strong positive correlation between student involvement in makerspaces and engineering design self-efficacy [36]. This could be because highly motivated and confident students are more likely to become involved in makerspaces or because makerspaces improve students’ motivation and confidence. Additionally, students who participated in university makerspaces were found to be less anxious about performing

engineering design related tasks [37], to have higher expectations of success [3, 5], and to have higher GPA's in engineering courses [38]. On top of this, requiring makerspace usage as part of an academic class increases student's likelihood of voluntarily continuing to be involved within the space [36].

A study conducting interviews at six university makerspaces across the United States showed that makerspaces provide students a wide array of affordances including the opportunity to complete hands on, iterative projects with real impact [7]. Students spoke of how makerspaces improved their communication, creativity, teamwork, and engineering skills [6, 7]. Innovation is fueled in makerspaces due to intrinsically motivated participants, unstructured activities, and diverse, multi-disciplinary culture [39]. Makerspaces also provide students with an environment where it is permissible to experiment and a sense of autonomy is encouraged [7, 8].

Longo *et. al.* notes the positive impact university makerspaces have on both the individual student and the university as a whole. According to a survey sent to engineering deans and chairs, makerspaces may help make engineering attractive to a diverse group of students and improve student retention in engineering [9]. Makerspaces have been highlighted as “hubs of community” [40] where makers gather together with likeminded individuals to enjoy simply making something new. Similarly, students note that makerspaces provide a sense of comfort and belonging as well as a location for social gathering where they can meet others with similar interests [7].

2.3 Makerspace Barriers to Entry and Sense of Belonging

Despite the vast benefits available to those who make use of academic makerspaces, many students still face both real and perceived barriers to entry based on factors such as gender, race, major, and prior experience that make them hesitant to enter (or prevent them from entering) such spaces. Common barriers to entry include lack of knowledge [23, 41-43], unfriendly or unknowledgeable staff [41, 44], an intimidating atmosphere [23, 43, 45], unclear membership pathways [25, 44, 46], and lack of information regarding equipment usage [43]. Bravo *et. al.* summarizes other potential barriers such as cost, eligibility requirements, hours of operation, physical location, makerspace size, and financial status of the user [44]. All these factors should be carefully considered when running a makerspace, and special attention should be given to them during times of increased restriction when their effects may be heightened.

Many students don't enter or stick around makerspaces due to a lack of sense of belonging [44, 47, 48]. This is especially true for underrepresented groups such as female [23, 42] or non-STEM students [49] who may not fit in with the student and staff makeup of these spaces [25]. According to Maslow's Hierarchy of Needs, people are motivated by a need to belong [50]. When students feel as though they don't belong in a space, they fail to fully reap the benefits afforded. Lack of belonging at school and in engineering may also hurt their academic performance, self-efficacy, and persistence in their major [51-53].

Han *et. al.* conducted a study examining makerspace continuance as a result of intrinsic motivation and therefore of autonomy, competence, and relatedness [54]. These three facets of intrinsic motivation are supported by technical, economic, and social

support, but it was found that the current levels of social and technical support in some makerspaces is not sufficient to supply the psychological need for competence [54].

Prior work has examined various solutions to increasing diversity and equitable makerspace participation. One effective pathway to makerspaces is face to face invitation by peers, makerspace staff, or educators [24, 46]. Other suggestions include offering sufficient and thorough training for new users [42, 43, 55], displaying student projects [56], hosting diverse workshops [43, 49], and offering events tailored to specific audiences – such as a service project or a ladies night [43, 57]. Research specifically focused on women makers emphasizes the importance of approachable and clearly defined leadership [43, 56], apprenticeship [24], women role models [45], and female centric considerations such as offering hair-ties in addition to safety glasses [56]. However in all of these examples, entrance requirements must still be clearly laid out [46], and multipronged approaches are recommend as often a single intervention proves inadequate [24].

2.4 Effects of COVID-19 on College Students and Academic Makerspaces

The COVID-19 pandemic presented a variety of hardships for some college students including food insecurity, financial trouble, return to volatile home circumstances, and added domestic responsibilities [58]. Difficulty in living arrangements was a large factor impacting student's confidence in learning during this time [59]. Students also missed out on ordinary collegiate experiences both inside and outside the classroom that have been shown to effect sense of belonging [58] and thus social, psychological, and academic outcomes [51-53]. Social support is directly related to well-being and COVID forced students to change their typical methods of connecting [60].

The shutdown surrounding the COVID-19 pandemic also provided immense difficulty for makerspace administration. Makerspaces thrive off community, collaboration, and hands-on experience, all of which were hard to generate during this time. Many professors were halfway through teaching courses that relied on makerspace usage. These faculty members were required to be creative and innovative as they sought to keep their students safe, while minimizing impact to education. Some worked with the makerspace staff to implement a use request system [61]. Others shifted to increased emphasis on literature review and engineering analysis instead of physical prototyping [61]. One school created “Garage in a Box” tool kits where students who did not have access to simple tools at home could receive a box of loaner tools from the makerspace [61]. Similarly, another makerspace provided maker kits that contained all the materials and tools necessary to complete a project at home (from sewing projects to AR/VR projects) [62]. A unique approach implemented at one school was remote control of digital fabrication machines such as laser cutters, 3D printers, and vinyl cutters [63]. Students could remote into the computer to set up and start their parts and cameras were arranged such that they could watch the process. The downside of this method was that an onsite operator was still needed to clear finished parts, load stock material, perform necessary maintenance, and observe machine safety [63]. It was found that instructional mode didn’t change students’ interest and enjoyment of engineering, but it did decrease their sense of belonging and sense of practicality in engineering [64], both of which are improved in academic makerspaces.

When students began returning to college campuses in Fall 2020, some makerspaces re-opened to students, but with very different guidelines and functionality. Many increased

their cleaning protocols, enforcing rules such as daily cleaning times, workbenches for backpacks, and wipeable covers on computer keyboards [27, 28, 63]. Universities also went to great efforts to space out students in makerspaces by adding occupancy limits, separating workbenches, using acrylic barriers, rearranging equipment, and adding floor markings to direct traffic through the space [27, 28]. Some started or continued to use hybrid training models such as videos uploaded on the school's learning management system [27, 63]. Additionally, many schools utilized sign-in and reservation systems so that students could reserve space to work ahead of time [27, 63].

While makerspaces are not intended to function as mass manufacturing sites, many were used at the start of the pandemic to produce PPE as demand soared [27, 65]. In some cases, makerspaces were used to design injection molding or die cut tooling while actual production was handled elsewhere [65, 66]. Others manufactured and tested respirators on site [66].

2.5 Makerspace Research Methods

The three main methods of data collection that have been used in past studies on academic makerspaces are sign-in systems [10-12], interviews [11, 13, 14], and surveys [10, 12, 13, 15]. Collecting sign-in data is the most common of these with most makerspaces implementing some form of electric sign-in system [67]. Students may be asked to swipe their college ID card [10, 67, 68], enter a people counting system such as a turnstile [10, 12, 13], or manually login via a tablet or computer [10, 11]. When using ID systems, students may swipe when entering the makerspace and/or before using specific equipment [68]. An appeal of this method is that it can be carried out as a normal part of

makerspace operations. Once properly set up, no additional effort is needed to collect data. If the system is well integrated into the makerspace, this allows for collection of large quantities of data that represent the makerspace population well. However, this method doesn't accurately account for duration of tool usage and may be misused if one person signs in on behalf of a group [68].

Interviews take more time and effort to implement, but provide qualitative data that is not represented by sign-in systems [11]. Anecdotal testimonies are especially helpful in understanding student motivations and experiences. Interviews are frequently transcribed and coded in order to understand overarching themes [14]. The interviews can also be supplemented with user observations [11]. A variant of this method is the use of feedback and testimonial forms that are open ended and often anonymous ways for students to provide their thoughts [11]. A key limitation of this method is number of participants. Given the time involved for the interview and the interviewee, it can be challenging to get a sufficient sample. Additionally, this type of data is not generally collected by makerspaces as part of their typical operations.

Finally, user surveys are beneficial means for data collection because they can be both qualitative and quantitative in nature and provide large sample sizes. Surveys range in length and purpose and allow wide varieties of questions to be asked. This gives insight into student motivations, equipment usage, and programming needs. When using surveys, researchers should be wary of potentially low accuracy in user reported frequency data [69]. This can be somewhat alleviated by focusing on more open-ended periods of time (e.g. on a general day vs yesterday) [70]. While survey length itself is not directly correlated to response accuracy [71], it can hurt the number of respondents. Additionally, survey

administrators should be aware that certain groups of people such as females and high performers are more likely to take voluntary surveys while those with more enterprising or artistic personalities are less likely to participate [69].

CHAPTER 3. METHODOLOGY

3.1 Research Locations

Two university makerspaces were examined as case studies. While both makerspaces are located at large R1 universities, their makerspaces are very different in purpose and operation. Table 1 summarizes some of these differences. For distinction purposes, the universities are referred to as School A and School B.

Table 1: Makerspace Structure at School A vs School B

	School A	School B
Staffing Structure	Run by paid staff, some of whom are students	Run by student volunteers
Location	General engineering building	Mechanical engineering building
Users	Undergraduate engineering students, select graduate students	Any students, faculty, or staff
Usage Types	Academic projects, student competition teams	Any class, research, club, or personal projects
Training Requirements	Initial safety training, advanced fabrication training	Safety agreement, other tools trained on a case-by-case basis depending on user needs
PPE Requirements	Safety glasses, closed toed shoes, and pants that cover the shoelaces are required to enter any part of the space.	Safety glasses and hair pulled back are required for wood and metal shops. No PPE requirements for main area.

School A is a large, public research university in the Southwest United States. The makerspace is a 61,000 ft² facility located inside a general engineering building and includes a full machine shop. Free membership is available for undergraduate engineering majors, and paid access is permitted on rare occasions for graduate students conducting research experiments. Eligible students may gain access to the design and build regions

after completing an online orientation and passing a safety quiz. This allows them to use electronics benches, 3D printers, hand tools, project workspaces, CAD computers, and some wood working tools. Additional training is required to gain access to the fabrication space which includes welding tools and metal fabrication equipment such as mills, lathes, and waterjets. Undergraduate engineering students may also submit service requests to have a part fabricated by trained machinists. The makerspace is primarily staff run, but some student workers are paid to help carry out fabrication requests and give tours. The facility may only be used for class and competition team purposes, but students are welcome to attend free workshops to learn how to use the tools regardless of class enrollment or club participation. Any person who enters any part of the space is required to be wearing safety glasses, closed toed shoes, and long pants that cover the shoelaces. Students are given a 3D print filament stipend, but otherwise are expected to bring their own materials.

School B is a large, public research university in the Southeast United States. The 5482 ft² makerspace is in one of the mechanical engineering buildings, but is open to any students, faculty, or staff members. Adjacent to the makerspace is a 6,235 ft² machining mall that contains lathes, mills, EDMs, and other similar equipment operated by machinists. The machining mall is unassociated with the makerspace but exists to fabricate parts for research purposes. They also provide equipment training on tools such as metal lathes and manual mills for students who are interested. The makerspace may be used for academic, research, club, or personal purposes without cost, but they are not permitted to sell anything that they make within the space. The only entry requirement is that students sign a safety agreement. Most tools are available for general use when someone enters, but

some of the more advanced machines including the mills, lathes, resin 3D printers, embroidery machine, and circuit board plotter require advanced trainings prior to independent use. These advanced trainings can be given when a user walks in if there are qualified staff members available or scheduled using QR codes posted in the space. The makerspace is run by student volunteers who staff the space in exchange for after-hours access to the equipment. The students on staff teach new users how to operate tools that they are not familiar with and advise them on their projects. Users must bring their own wood or metal for subtractive manufacturing projects, but 3D printer filament, threaded fasteners, generic electronics components, and craft consumables such as yarn or buttons are all made available for free. Additionally, a store is located outside the space where students may purchase commonly used materials such as 2x4's, plywood, and paint. To enter the wood or metal shops, students are required to wear safety glasses and closed toed shoes and tie back long hair. They are also not permitted to wear loose clothing. Safety glasses must also be worn to operate soldering equipment.

Table 2 summarizes all the makerspaces available to students at School A and School B. While only the makerspaces highlighted in grey were studied, it is important to recognize the alternative opportunities that students received. Classroom laboratories, such as an industrial design studio are not included since they are not available for use outside of specific classes.

Table 2: Makerspaces Available for Student Use at School A and School B

School A		
Makerspace Location	Makerspace Capabilities	Who Has Access
Engineering Building	Wood tools, metal tools, laser cutter, 3D printers, electronics, water jet, crafting tools, welding, CAD stations	Undergrad Engineering Students
Mechanical Engineering Building	3D printing, laser cutter (added Spring 2023)	Mechanical Engineering Students
Architecture Building	Wood tools, metal tools, laser cutter, plasma cutter, water jet, welding	Any students, faculty, or staff
Architecture Building	3D printers, laser cutter	Any students, faculty, or staff
School B		
Makerspace Location	Makerspace Capabilities	Who Has Access
Mechanical Engineering Building	Wood shop, metal shop, laser cutters, 3D printers, electronics, PCB mill, water jet, wood & metal CNC, crafting tools, bike tools, welding, CAE station, paint booth	All students, faculty, and staff
Electrical and Computer Engineering Building	Electronics, PCB mill, wood/metal machine shop, laser cutter, 3D printer, plasma cutter, crafting tools, paint booth	All students, faculty, and staff
Aerospace Engineering Building	Wood shop, metal shop, laser cutter, 3D printer, electronics, composites tools	All students, faculty, and staff
Material Science and Engineering Building	3D printer, material characterization, processing, & measurements tools	All students, faculty, and staff
Technology Research Building	Crafting tools, 3D printers, electronics	All students, faculty, and staff
Biomedical Engineering Building	Laser cutter, 3D printers, vacuum former, resin casting equipment, CNC mill & lathe	Biomedical engineering students
Library	Adobe software suite, poster printing, video and audio recording studio	All students, faculty, and staff

3.1.1 Classes that Use the Makerspace

Both makerspaces get used for many undergraduate classes. At School A, students are required to use the specific makerspace to complete their projects while at School B, they are assigned projects that would be hard to complete outside the makerspace but are not specially tied to it. Table 3 outlines the classes that most often use the makerspace at the two schools. It should be noted that there are other students who use School B's makerspace for elective coursework. At School A, the Engineering Graphics course is a required course that teaches introductory SolidWorks. The Computer Aided Engineering course is an elective students can take to learn more advanced SolidWorks techniques.

Table 3: Classes that Use the Makerspace at School A and School B

School A				
Course	Major	Year Generally Taken	Required?	Tools Used
Engineering Graphics	Mechanical Engineering	2 nd	Yes	3D Printers/ Scanners
Materials and Manufacturing	Mechanical Engineering	3 rd	Yes	Lathe, Mill, Bandsaw, Hand Tools, 3D Printer
Computer Aided Engineering	Mechanical Engineering	4 th /5 th	No (Elective)	Metal Tools (vary based on project)
ME Senior Design	Mechanical Engineering	4 th /5 th	Yes	Varies based on project
EE Senior Design	Electrical Engineering	4 th /5 th	Yes	Varies based on project
Manufacturing Methods	Industrial and Systems Engineering	2 nd	Yes	3D Printing, Others not specified
School B				
Course	Major	Year Generally Taken	Required?	Tools Used
Engineering Graphics	Mechanical Engineering	1 st	Yes	3D Printers

Table 4 Continued

Sophomore Design	Mechanical Engineering	2 nd /3 rd	Yes	3D Printers, Laser Cutters, Wood and Metal Tools
Senior Design	Various Engineering Disciplines	4 th /5 th	Yes	Varies based on project

3.1.2 COVID-19 Restrictions

Due to COVID-19, conditions were not the same in the makerspaces across the different semesters. The restrictions at each university are summarized in Table 5 while the restrictions at each makerspace are summarized in Table 6. Data was not collected in Fall 2021 because the universities and makerspaces were still heavily restricted.

Table 5: University Wide COVID-19 Restrictions

	School A	School B
Fall 2020 and Spring 2021	Most classes were fully online, but some in person classes were available. Masks were expected and regular COVID-19 testing was encouraged. Contact tracing and isolation options for students who contracted or were near those who had COVID-19.	Most classes were fully online, but some lab classes followed a hybrid format. Weekly COVID-19 testing, and face masks were encouraged. Contact tracing and isolation options for students who contracted or were near those who had COVID-19.
Spring 2022	Primarily back to normal, but masks heavily encouraged. Remote options still available for most classes, but students were expected to pay an extra fee to enroll in them.	Most classes resumed in person learning, but a handful were still remote. Mask usage and weekly COVID-19 testing still encouraged.
Fall 2022 and Spring 2023	Pre-COVID conditions. Extra fee still required for online classes.	Pre-COVID conditions.

Table 6: Makerspace COVID-19 Restrictions and Protocols

	School A	School B
Fall 2020 and Spring 2021	Hangout areas/study spaces closed. One student per group project allowed inside. Students had to sign up to use the space 24 hours in advance.	Rearranged to separate workstations. Plexiglass barriers used to separate tools like laser cutters and sewing machines. UV cabinets used to sanitize safety glasses. Capacity limits enforced. Space sanitized daily as part of shut down procedures.
Spring 2022	No COVID-19 restrictions	Safety glasses sanitized with UV cabinet.
Fall 2022		No COVID-19 restrictions
Spring 2023		

3.2 Survey Contents

Data for this study were collected through a series of online surveys that asked students questions about tool usage, motivations for using the makerspace, prior makerspace involvement, and demographics. For the tool usage section, students were first asked to select the tools that they had used from a list of *general* tool categories such as wood tools, or 3D printers. Based on the general tools they selected, survey logic was used to ask them additional questions about the *specific* tools they used in each of those general tool categories. Examples of specific tools include the bandsaw for the wood room, or the Ultimaker for the 3D printers. A list of the general tool categories and related specific tools are listed in Table 7. Some of the general tool categories, such as the laser cutter or paint booth, are comprised only of one general tool and do not have any corresponding specific tools. While the general tool categories are the same at both universities, the specific tools available at each school vary. Table 9 shows the tools unique to each university's makerspace. Additionally, the specific tools listed on the survey vary from semester to

semester as tools were added/removed from the space. Most of the analysis deals only with the general tool categories as these are comparable across all schools and all semesters. All students who completed the survey were given a \$20 gift card.

Table 7: General Tool Categories and Corresponding Specific Tools

General Tool Category	Specific Tools – School A	Specific Tools – School B
3D Printing	Ultimaker, Dremel DigiLab, SLS Formiga, Stratasys, Resin Printers, 3D Scanner, Studio System Printer (Metal), Scanner 3D, Don't Know*, Other	Ultimaker, SLS Formiga, Resin Printers, Stratasys, 3D Scanner, Don't Know*, Other
Metal Tools	Manual Mill, CNC Mill, Manual Lathe, CNC Lathe, Waterjet, Drill Press, Bandsaw, Electric Discharge Machine, Surface Grinder, Injection Molder, Vacuum Former, Hydraulic Press, Metal Shears, Welding Equipment, Other	Bandsaw, CNC Mill, Manual Mill, CNC Lathe*, Injection Molder*, Vacuum Former*, Manual Lathe, Drill Press, Waterjet, Belt Sander, Polishing Wheel, Sheet Metal Brake*, Cold Cut Saw*, Metal Shears*, Other
Craft Tools	Vinyl/Paper Cutter, Foam Cutter, Sewing Machine	Embroidery Machine, Hot Wire Foam Cutter, Sewing Machine, Vinyl/Paper Cutter, Button Maker*, Other
Electronics	Circuit Board Plotter, Multimeter, Power Supply, Soldering Equipment, Oscilloscope, Logic Analyzer, Other	Circuit Board Plotter, Multimeter, Power Supply, Soldering Station, Oscilloscope, Logic Analyzer, Function Generator*, Other
Wood Tools	CNC Wood Router, Hand Router, Drill Press, Table Saw, Miter (Chop) Saw, Hand Sander, Bandsaw, Belt Sander, Circular Saw, Jigsaw, Vacuum Former, Other	Bandsaw, Belt Sander, Circular Saw, Miter (Chop) Saw, Jigsaw, CNC Wood Router, Drill Press, Planer, Hand Router, Sander, Table Saw, Jointer*, Wood Lathe*, Other

Table 8 Continued

Handheld Tools	Hammer, Pliers, Vice Grips, Clamp, Screwdriver, Hand Drill, Angle Grinder, Chisel, Measuring Tape, Table Vice, Glue Gun, Wire Cutters, Hand Saw, Dremel, Tap & Dye, Scissors, Tin Snips, X-ACTO Knife, Other	Hammer, Pliers, Vice Grips, Clamp, Screwdriver, Hand Drill, Angle Grinder, Chisel, Measuring Tape, Table Vice, Glue Gun, Wire Cutters, Hand Saw, Dremel, Tap & Dye, Scissors, Tin Snips, X-ACTO Knife, Other
Laser Cutter		
Work Areas*	CAD Station, Construction Station, Workbench, Mobile HDTV, Whiteboard	CAD Station, Workbench/Tables, Whiteboards, Other
Social Activities	Studied, Hung Out, Met with a Group	Studied, Hung Out, Met with a Group
Help	Helped by another student, Helped by a staff member, Helped someone else	Helped by another student, Helped by a staff member, Helped someone else
Paint Booth		
Other	User Defined	User Defined

* Denotes tools was not listed as an option on all semesters of the survey

Table 9: Tools Unique to Each School

School A	School B
Metal 3D Printer	Carbon Fiber 3D Printer
Hydraulic Press	Polishing Wheel
Electric Discharge Machine (EDM)	Embroidery Machine
Construction Station	Foam Cutter
Mobile HDTV	Bike Tools
	Planer

3.3 Recruitment Methods

Survey recruitment looked different from semester to semester and between schools due to changes in operation over the semesters. In Fall 2020 and Spring 2021, researchers at each school recruited survey participants in classes that either required students to use the space or required projects that allowed students to use the space. This was done through in-person announcements, virtual Zoom announcements (while classes were online during

the pandemic), and written announcements sent through the school's learning management system. At School A, students were recruited from classes in engineering graphics, materials and manufacturing, advanced computer aided engineering, manufacturing processes, electrical engineering capstone design, and mechanical engineering capstone design. At School B, students were recruited from courses in engineering graphics, sophomore mechanical engineering design, and mechanical/interdisciplinary capstone design. Students who completed the Entry/Exit surveys described in prior work [72] were also invited to participate in the end of semester survey. Beginning in Spring 2021 at School A, any student who had signed into the makerspace in the last year was emailed the end of semester survey to complete if they were interested.

In Spring 2022, students who used the makerspace at School A were once again emailed the survey. At School B, the sign in system was not used consistently so undergrad researchers stood outside the makerspace and asked students to sign up to complete the end of semester survey during the last two weeks of classes. They paid students \$1 in cash for signing the consent form and agreeing to take the survey and the \$20 gift card previously mentioned if they actually completed the survey once it was sent out. The survey link was also sent out to the same classes as before at School A, and to mechanical/interdisciplinary capstone design students at School B.

In Fall 2022, the sign-in system at School B was experiencing much more consistent use. The survey was sent via email to all the students who signed into the space at some point over the semester. The survey was not sent to students enrolled in capstone this semester, but any capstone student who used the space would have been included in the distribution list. Recruitment at School A remained the same as Spring 2022. Finally, in

Spring 2023, data collection mimicked the procedures used in Spring 2022 at both schools to get as comparable of a sample as possible for across semester analysis.

CHAPTER 4. MAKERS AND MAKING PATTERNS AT SCHOOL

A AND SCHOOL B

This chapter gives a high-level overview of the survey participants and usage trends examined by combining all five semesters of general tool usage survey data.

4.1 Participant Demographics Overview

Table 10 outlines the number and percentage of participants in different demographic categories for each school. A chi-squared test was performed to compare the participant quantities for the two schools and these results are also presented in the table. Significant results are marked with an asterisk. While very similar recruitment methods were used at each school, the participant breakdown varied substantially, as can be seen by the number of significant results. Much of this can be attributed to the differences between the two schools, such as number of Hispanic students, or the differences between the two makerspaces, such as the percentage of students who used the space for class. However, the participant distribution should be kept in mind when examining the results presented in the remainder of this work.

Table 10: Demographic Breakdown of Participants at School A and School B

		School A N = 463		School B N = 529		X ²	P
		#	%	#	%		
Gender	Male	311	67%	314	59%	6.467	0.011*
	Female	127	27%	166	31%	1.851	0.174
	Other	0	0%	5	1%	4.398	0.036*
	Prefer Not to Disclose	25	5%	44	8%	3.248	0.071
Ethnicity	Hispanic	99	21%	55	10%	22.720	<0.001*
	Non-Hispanic	339	73%	447	84%	19.096	<0.001*

Table 11 Continued

	Prefer Not to Disclose	21	5%	27	5%	0.173	0.677
Race	White/Caucasian	303	65%	266	50%	23.198	<0.001*
	Black or African American	8	2%	26	5%	7.577	0.006*
	American Indian or Alaskan Native	9	2%	2	0%	5.520	0.019*
	Native Hawaiian/Pacific Islander	1	0%	2	0%	0.215	0.643
	Middle Eastern	11	2%	9	2%	0.569	0.451
	Asian	109	24%	211	40%	30.184	<0.001*
	Other	11	2%	14	3%	0.074	0.786
	Prefer Not to Disclose	25	5%	27	5%	0.043	0.835
Major	Aerospace Engineering	22	5%	47	9%	6.517	0.011*
	Biomedical Engineering	14	3%	21	4%	0.649	0.420
	Chemical Engineering	1	0%	10	2%	6.312	0.012*
	Computer Engineering	12	3%	12	2%	0.109	0.741
	Electrical Engineering	73	16%	19	4%	43.497	<0.001*
	Industrial Engineering	26	6%	7	1%	14.145	<0.001*
	Material Science/Engineering	5	1%	5	1%	0.045	0.832
	Mechanical Engineering	263	57%	307	58%	0.153	0.696
	Nuclear Engineering					1.754	0.185
	Other	47	10%	98	19%	13.874	<0.001*
Class/ Studying	Used makerspace for a Class This Semester	361	78%	332	63%	27.126	<0.001*
	Used Makerspace for Capstone This Semester	166	36%	147	28%	7.436	0.006*
	Used Makerspace for Non-Capstone Class This Semester	234	51%	213	40%	10.530	0.001*
	Studied in the Makerspace This Semester	57	12%	131	25%	13.536	<0.001*
First Gen	First Gen College Student	119	26%	88	17%	0.086	0.769
Transfer	Transfer Student	66	14%	70	13%	0.288	0.591
Class Level	Freshman (By Credit Hour)	21	5%	41	8%	12.992	<0.001*
	Sophomore (By Credit Hour)	110	24%	105	20%	18.803	<0.001*
	Junior (By Credit Hour)	67	14%	93	18%	2.029	0.154
	Senior (By Credit Hour)	267	58%	314	59%	15.981	<0.001*
Year at School	1st Year (No Transfers)	23	5%	97	18%	39.883	<0.001*
	2nd Year (No Transfers)	147	32%	109	21%	0.295	0.587
	3rd Year (No Transfers)	66	14%	58	11%	1.368	0.242
	4th Year (No Transfers)	144	31%	86	16%	40.698	<0.001*
	5th Year (No Transfers)	34	7%	80	15%	0.460	0.498

4.2 General Tool Usage at School A and School B

4.2.1 Usage Compared by School

As previously discussed, the makerspace at School A was designed to support engineering courses and is primarily used for students working on class or club projects. On the other hand, the makerspace at School B supports some academic classes, but welcomes personal projects. Figure 1 summarizes the types of projects students had *ever* used the makerspace for. While class usage is higher at School A, students at School B have much higher usage in all the other categories indicating more diverse usage at this makerspace.

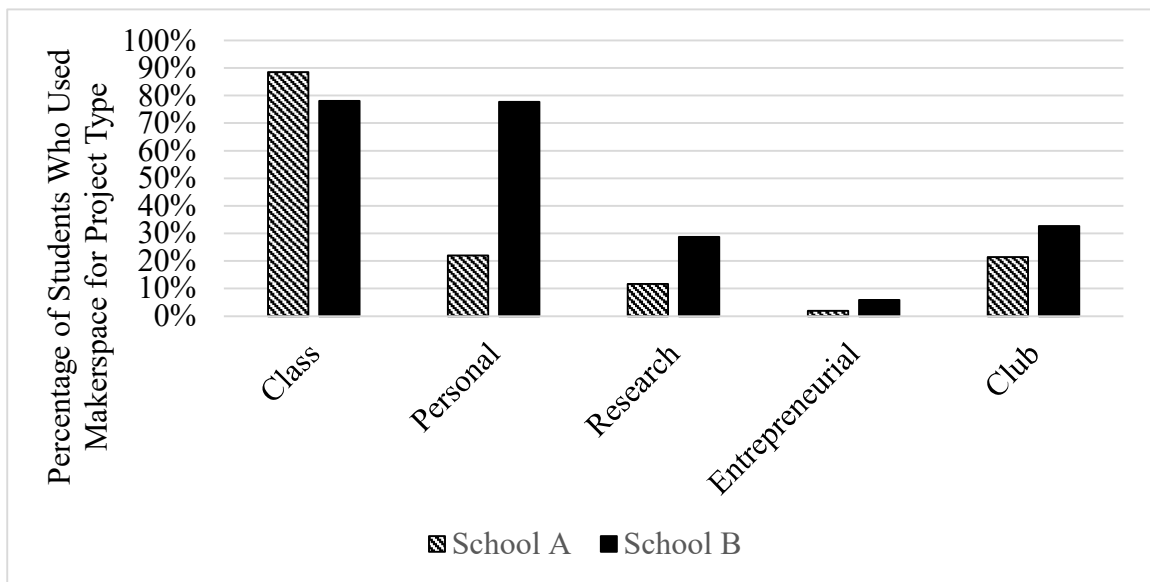


Figure 1: Project Usage Type at School A vs School B

Figure 2 summarizes the types of activities students had previously used a makerspace for. While slightly more students at School A collaborate on projects, most

other categories were higher at School B. The most popular activity at both schools was building something.

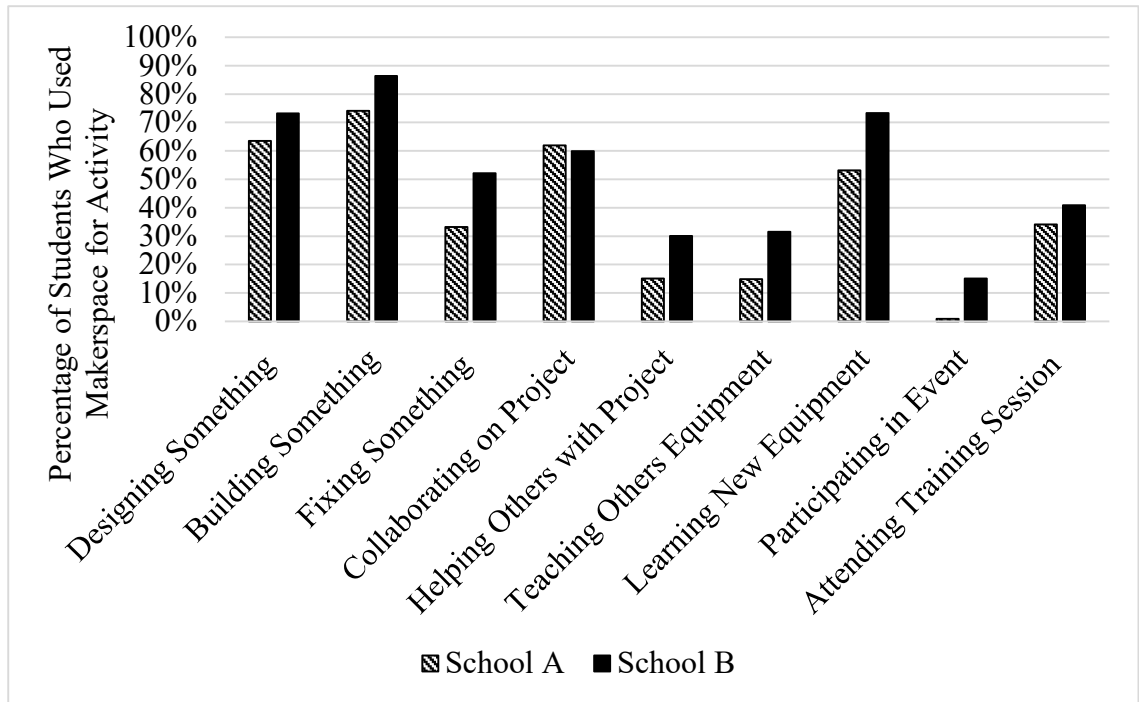


Figure 2: Popular Makerspace Activities at School A vs School B

Because the specific tools offered at each school are not identical, the metric most used throughout this thesis to describe student tool usage is percentage of survey respondents who used each general tool group. Figure 3 compares these results for School A and School B. Table 12 shows the results of a chi-square test. The black stars on the figure and the asterisks in the table represent statistically significant differences. Tool usage is statistically higher at School B for all categories except for metal tools, workstations, social activities, and the other category. The largest differences are seen for laser cutters and wood tools. On the other hand, there is nearly no difference between percent usage of metal tools. The high usage of metal tools at School A may be the result of several classes

that require students to use metal tools as described in Table 3. From this we learn that students at School B use a wider variety of tools while students at School A are more likely to come in and only use a few things, thus decreasing percent usage. For both schools, the highest percentage usage group is the 3D printer. This is helpful to know as the makerspace expands and seeks to attract more participants.

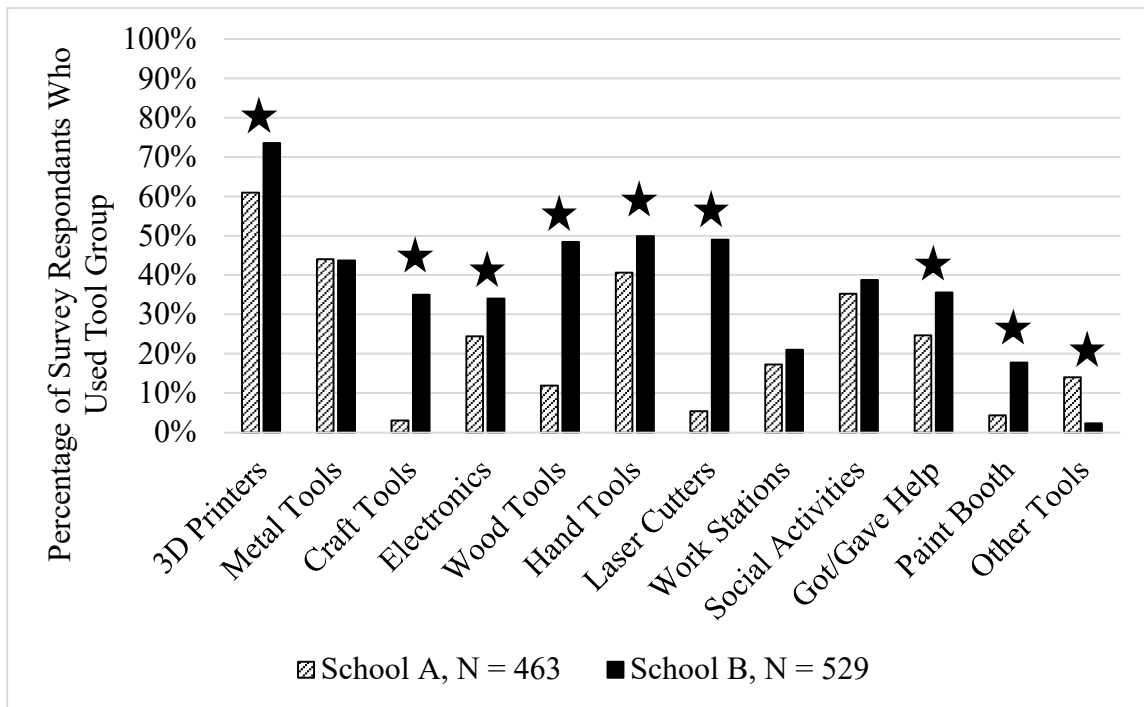


Figure 3: Percentage Tool Usage Between Schools

Table 12: Chi-Square Results for Between School Analysis

	3D Printers	Metal Tools	Craft Tools	Electronics	Wood Tools	Hand Tools	Laser Cutters	Work Stations	Social Activities	Got/Gave Help	Paint Booth	Other
n	992	992	992	992	992	992	992	938	992	992	938	992
df	1	1	1	1	1	1	1	1	1	1	1	1
X ²	17.988	0.016	157.147	10.98	152.955	8.611	229.291	0.288	1.331	13.896	35.838	47.777
p-value	<0.001*	0.901	<0.001*	<0.001*	<0.001*	0.003*	<0.001*	0.591	0.249	<0.001*	<0.001*	<0.001*

4.2.2 Usage Compared by Gender

Prior work in STEM fields and academic makerspaces has indicated a discrepancy between makerspace usage in men and women students [23, 24, 42, 45]. Figure 4 and Table 13 indicate that there is no such statistical difference at School A. This may be biased by the fact that students at School A are *required* to use the makerspace for many of their classes. It is unclear whether they would have used the makerspace at the same rate as their male peers if given the choice.

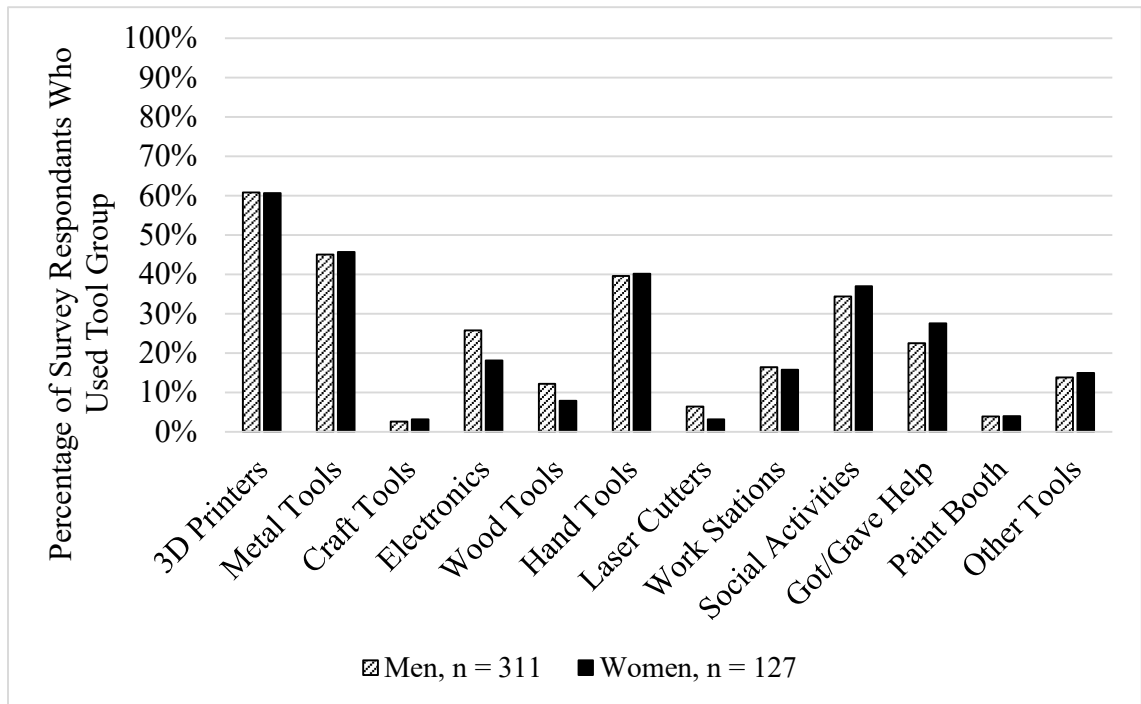


Figure 4: Tool Usage of Men vs Women at School A

Table 13: Chi-Squared Statistics for Tool Usage of Men vs Women at School A

	3D Printers	Metal Tools	Craft Tools	Electronics	Wood Tools	Handheld Tools	Laser Cutters	Work Stations	Social Activities	Got/Gave Help	Paint Booth	Other
n	438	438	438	438	438	438	438	388	438	438	388	438
df	1	1	1	1	1	1	1	1	1	1	1	1
X ²	0.001	0.061	0.298	3.136	2.218	0.014	1.875	0.525	0.205	0.949	0.347	0.048
p-value	0.978	0.804	0.585	0.077	0.136	0.906	0.171	0.469	0.651	0.33	0.556	0.826

Figure 5 and Table 14 depict the results at School B. Again, statistically different results are marked with a black star or asterisk. It is seen that men have a statistically higher percent usage of many tool groups, including 3D printers, metal tools, electronics tools, wood tools, and hand tools. Conversely, women have a statically higher percent usage of craft tools, an area that is traditionally associated with feminine skills. Interestingly, the less tool-oriented categories, such as workstations, social activities, and giving/receiving help show no significant difference between men and women.

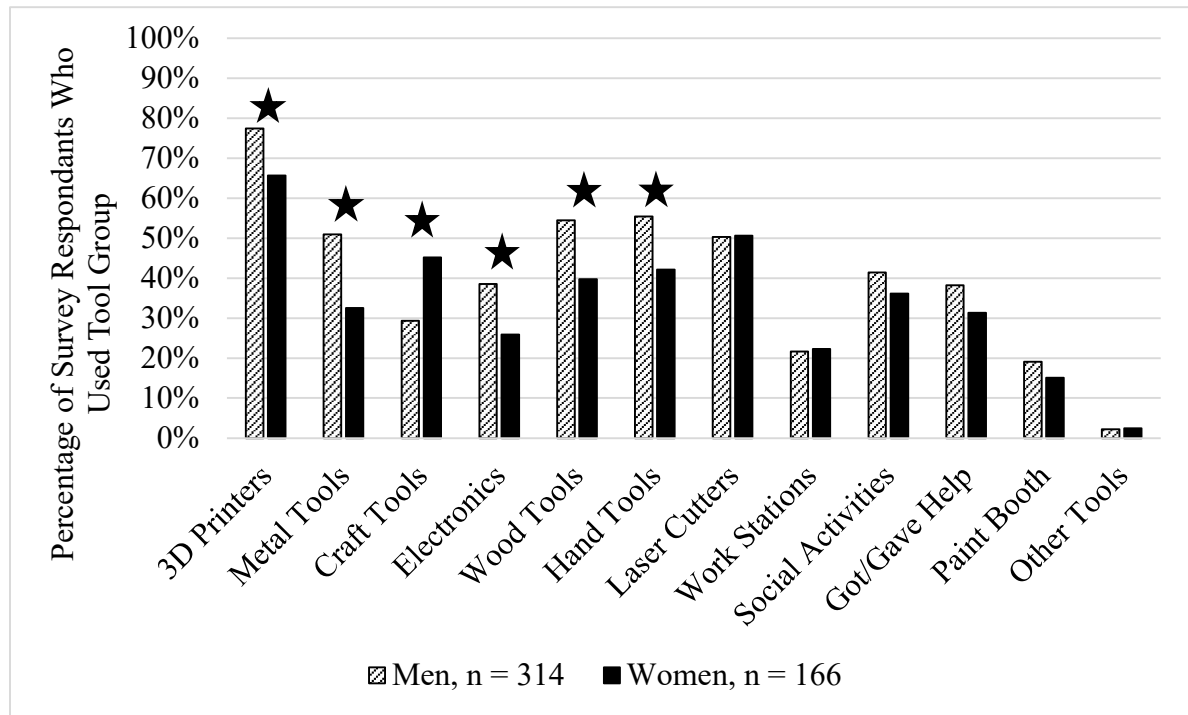


Figure 5: Tool Usage of Men vs Women at School B

Table 14: Chi-Squared Statistics for Tool Usage of Men vs Women at School B

Tool Usage based on Gender, School B												
	3D Printers	Metal Tools	Craft Tools	Electronics	Wood Tools	Handheld Tools	Laser Cutters	Work Stations	Social Activities	Got/Gave Help	Paint Booth	Other
n	480	480	480	480	480	480	480	480	480	480	480	480
df	1	1	1	1	1	1	1	1	1	1	1	1
X ²	8.158	15.305	12.603	7.932	9.732	7.947	0	0.016	1.367	2.378	1.283	0.013
p-value	0.004*	<0.001*	<0.001*	0.005*	0.002*	0.005*	0.997	0.9	0.242	0.123	0.257	0.908

4.2.3 Usage Compared by Race/Ethnicity

General tool usage was also analyzed based on race/ethnicity, and results are shown in Figure 6. At School A, the sample size allowed comparison between Hispanic students, White/Caucasian students, and Asian students. Survey participants could also denote that they were Black/African American, American Indian/Alaskan Native, Native Hawaiian/Other Pacific Islander, Middle Eastern, or Other, but the sample sizes were too small to compare these results. Similar to the gender analysis, there are no notable differences in tool usage across race/ethnicity at School A. While some races/ethnicities may be underrepresented in STEM programs, all that are enrolled are required to use the makerspace as part of class.

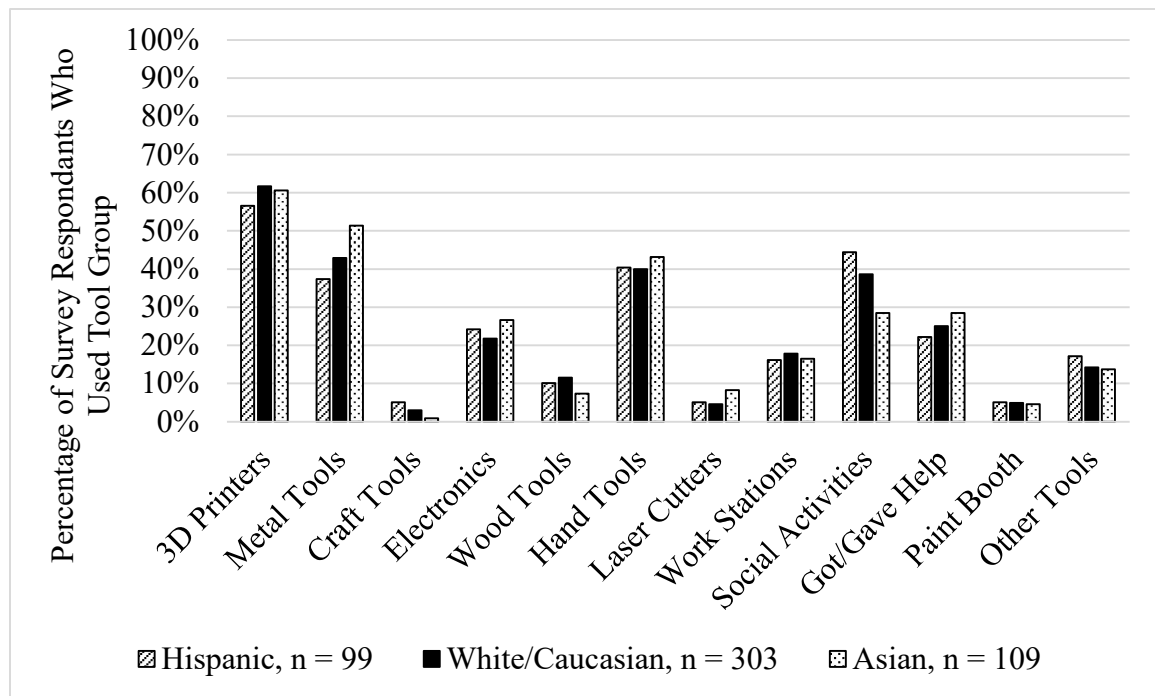


Figure 6: Tool Usage Compared by Race/Ethnicity at School A

At School B, the sample size allowed comparison between Hispanic students, White/Caucasian students, Asian students, and Black/African American students, though the same options were given as on the School A survey. These results are presented in Figure 7. Even though class usage is not required in the same way, there are still not many notable or consistent differences across the various races/ethnicities.

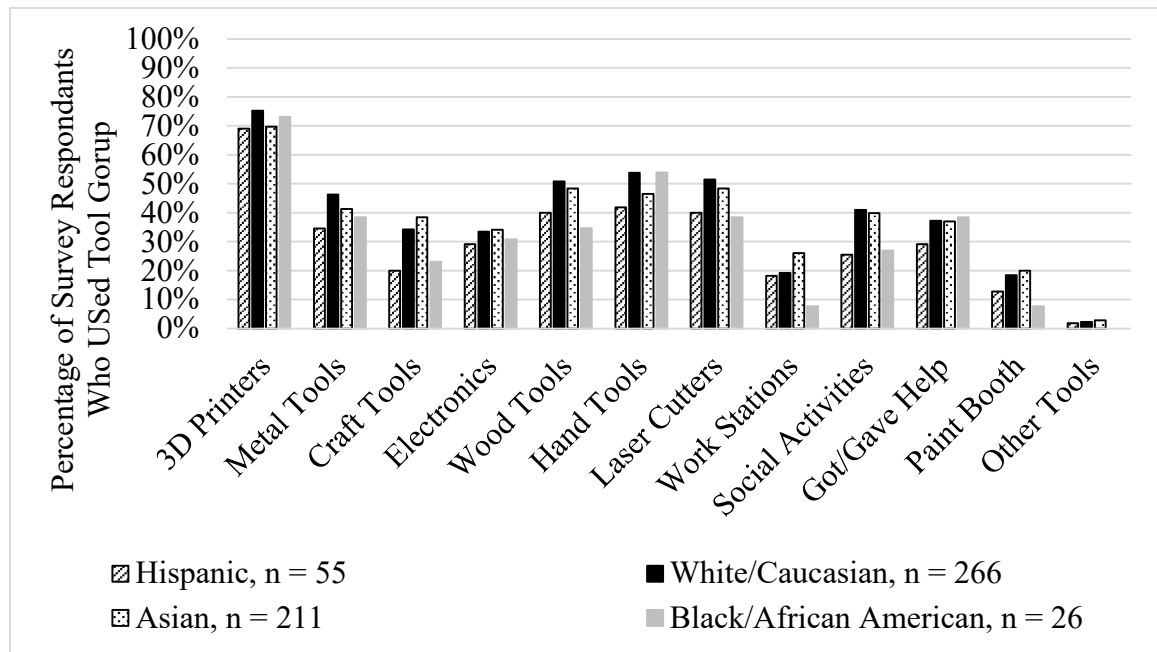


Figure 7: Tool Usage Compared by Race/Ethnicity at School B

4.2.4 Usage Compared by Major

Figure 8 and Figure 9 show tool usage by major for the two schools. The specific majors looked at change based on sample size of participants at each school. As expected, there are some very large differences in tool usage among majors, likely dictated by coursework. This affects not only the projects the students are expected to complete, but also the knowledge and skills that they are specifically taught in their classes. For example, electrical engineering students at School B may be more likely to use the electronics section

because their EE coursework assigns projects where the equipment would be beneficial, or because they have a higher level of knowledge of electronics and electronics equipment compared to their nonelectrical engineering major peers. At School A, there is huge variation in tool usage, which can most vividly be seen as the difference between ME students and EE students. At School B, tool usage is less affected by major, which makes sense given that it does not have to be used solely for class or club projects.

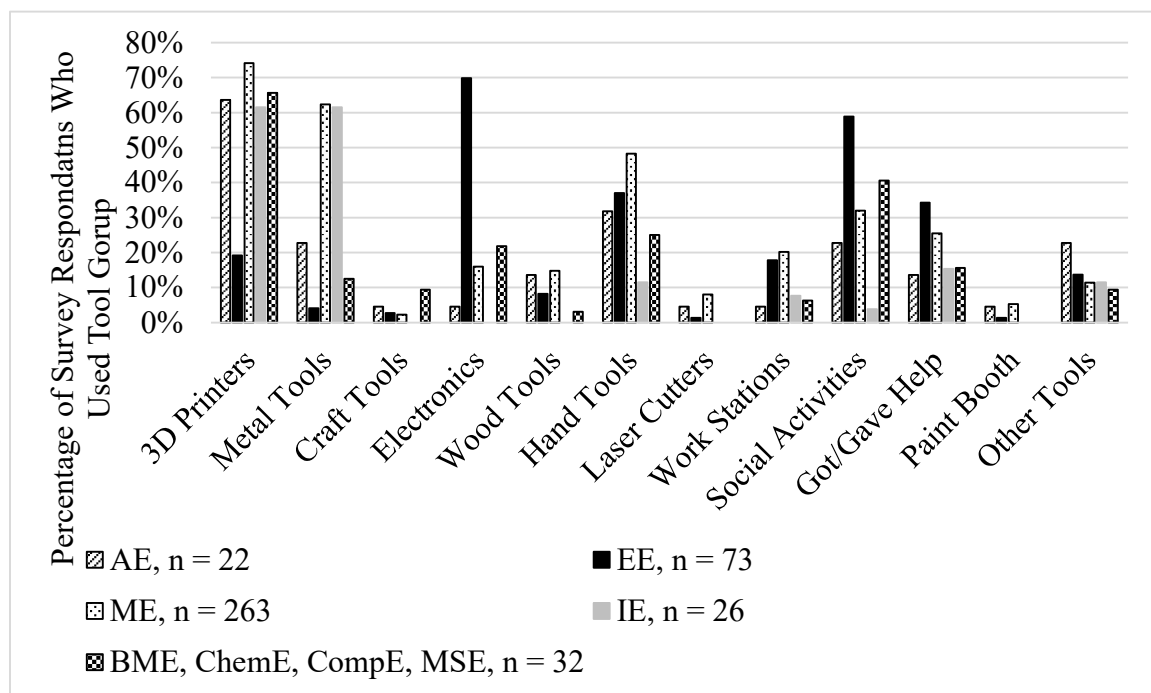


Figure 8: Tool Usage Compared by Major at School A

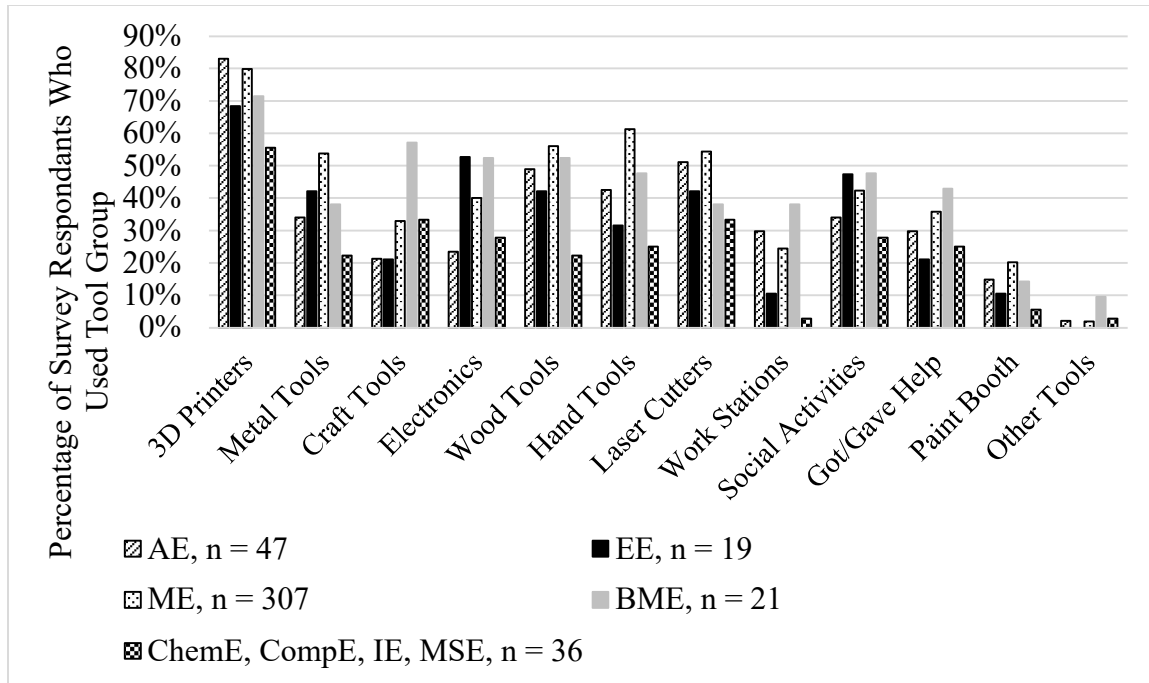


Figure 9: Tool Usage Compared by Major at School B

4.2.5 Usage Compared by Year in School

Analysis by major provides more tailored insight into how student tool usage changes by year in school. Here, mechanical engineering students are examined due to the large number of mechanical engineering survey participants, however similar analysis could be conducted for any major. Any students who transferred into the university were removed as their year at the school may not be indicative of their progress through the mechanical engineering curriculum and the number of these students was small with only 3 students at School A and 20 students at School B. Additionally, the 4th and 5th year students were combined because most senior level classes could be taken either year depending on the student's anticipated graduation date. Few 1st year students use the makerspace at School A, so they were also excluded from the analysis.

Figure 10 shows the percentage of mechanical engineering students who used each general tool category at School A. Black arrows are used to denote a tool was taught or used in a required class. Red arrows are used to denote a tool was taught or used in an elective class. Most tool groups, including wood tools, handheld tools, workstations, and social activities had increased percentage usage as students completed more years of school. Interestingly, metal tool usage peaked for 3rd year students and then declined slightly for 4th/5th year students. This is likely due to the materials and manufacturing course (listed in Table 3 in the methods section) that introduces students to several metal tools. Some tool categories, such as electronics and laser cutter, do not show large changes between years in school. This could be due to no mechanical engineering courses explicitly requiring students to use these tools. The percentage of students giving and receiving help increases drastically in year 3, when students are most likely to be using more complex machinery. It then plateaus for 4th and 5th year students which could indicate they have become more comfortable and competent in the space. The overall increase in tool usage as student progress through the curriculum indicates that once students are introduced to a tool, they are likely to use it in the future, regardless of whether it is required. For example, 2nd year mechanical engineering students use the 3D printers for their engineering graphics class and sometimes for their materials and manufacturing class. However, 3D print usage is highest in student's 4th/5th years when they may voluntarily be using it for capstone or other elective coursework.

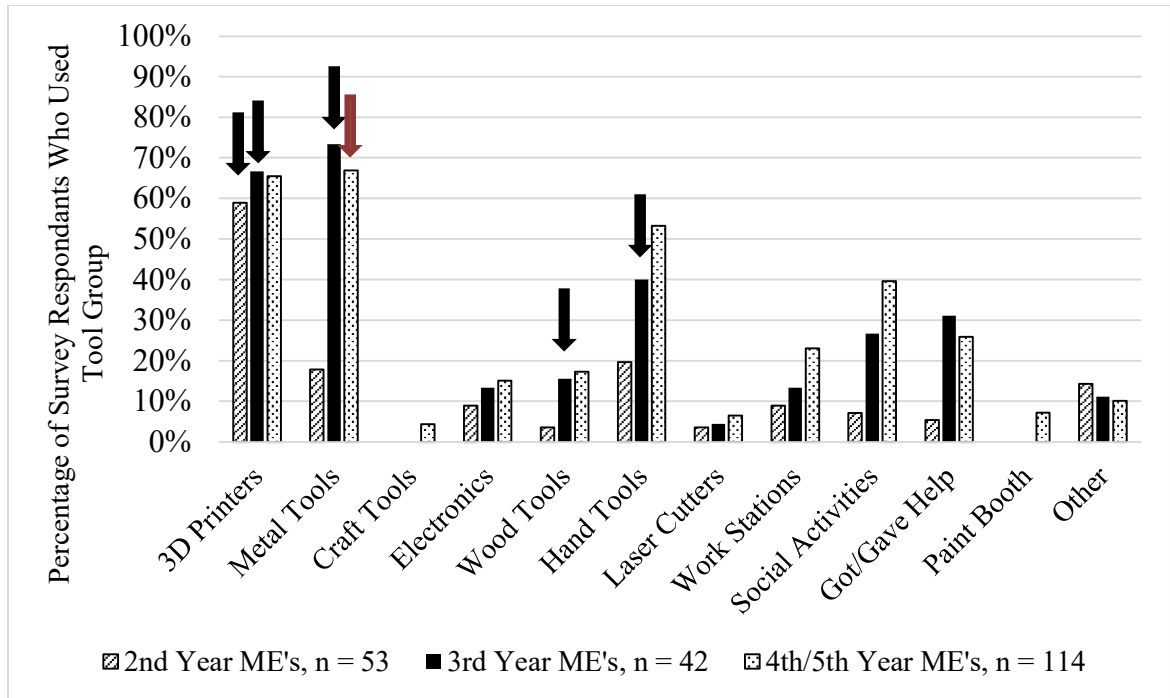


Figure 10: Tool Usage of Mechanical Engineering Students Compared by Year in School at School A

These patterns are not the same at School B (Figure 11). Tool usage is lower for 1st year students, but then remains more consistent 2nd year onward. This is attributed to the personal projects that students can work on. Despite the more stable trends, some tools still peak substantially in certain years. For example, 3D printer usage is at least 17% higher for 2nd year students, most likely due to their sophomore design class where 3D printed parts are heavily used. Similarly, electronics tool usage is over 20% higher for 3rd year students. Most mechanical engineering students at School B take an electronics lab class during their 3rd year.

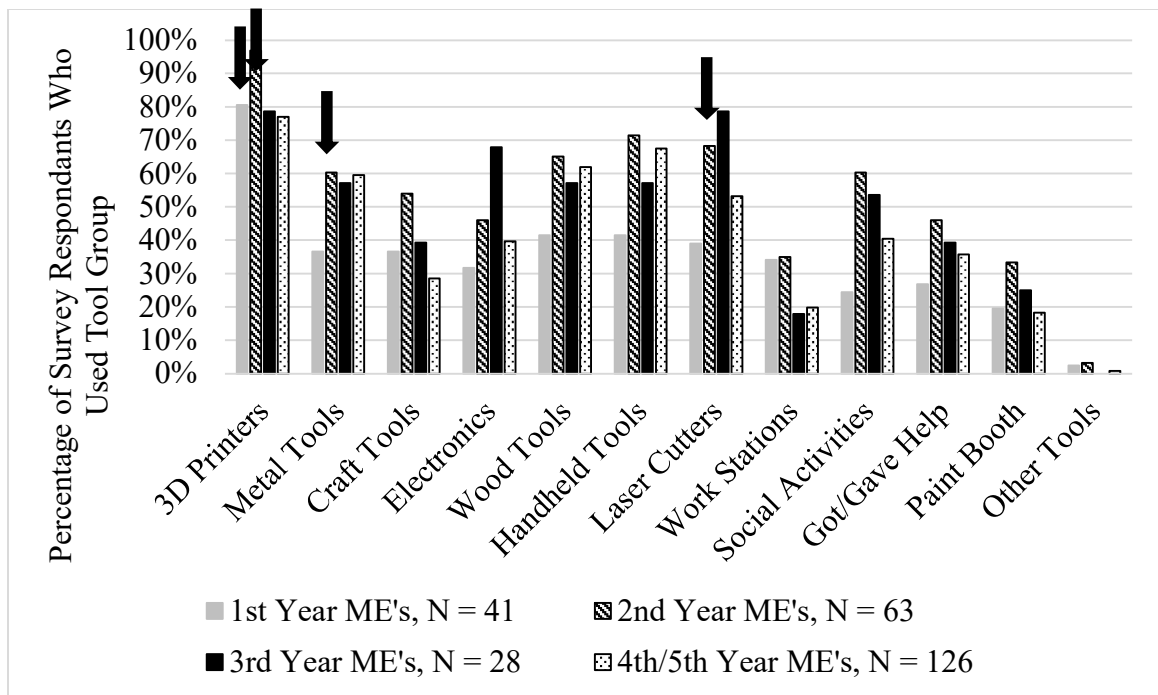


Figure 11: Tool Usage of Mechanical Engineering Students Compared by Year in School at School B

Figure 12 shows the percentage of students who use the space for personal projects vs class projects for each year in school. Initially personal project usage is higher, but in student's final year(s), a high percentage use it for class, most likely capstone design.



Figure 12: Class vs Personal Project Usage for Students at School B by Year in School

4.3 Discussion

While both makerspaces are found in engineering buildings at large R1 universities, their purposes and therefore their usages are very different. At School A, students may only use the space for class or club projects and therefore their usage varies substantially based on which classes they are currently enrolled in. In some senses, this model is more restrictive, but at the same time it encourages equal participation of all genders, races, ethnicities, and majors, and seems to overcome some of the barriers to entry that are seen in many other spaces. If this space were to allow personal projects for higher level students, they would likely see high usage due to all the required training and usage received in lower-level curriculum.

At School B, tool usage is in general higher for most tool categories and students engage in a much more diverse series of activities than their peers at School A. While a

few key classes make use of the space, much of the space's usage comes from research, club, and personal projects. The lower level of restrictions encourages some students to use the space more often, but at the same time is less effective in engaging a diverse group of students. Required class usage of certain tools is shown to be valuable at both schools and seems to encourage students to voluntarily use those tools for the remainder of their time in school.

CHAPTER 5. STUDENT TOOL USAGE DURING AND AFTER THE COVID-19 PANDEMIC

This chapter examines how makerspaces react to disruptions, which often manifest themselves in the form of increased restrictions. Makerspace response to COVID-19 is presented as a case study. Data in this section is for Spring 2021, Spring 2022, and Spring 2023. The fall semesters were removed so that the across semester analysis would be as comparable as possible.

5.1 Demographic Breakdown

Table 15 and Table 16 show the breakdown of students who participated each semester. While the percentage of students of different genders, races, and ethnicities remains similar, some statistically significant differences are still present despite using similar recruitment processes each semester. For School A, there is a 22% difference in the percentage of mechanical engineering students who took the survey each semester. Additionally, there is a 24% difference in percentage of students using the space for class and an 18% difference in students using the space for capstone. Finally, there is a 31% difference in students using the space for studying, though this is not surprising given the COVID-19 restrictions in Spring 2021. For School B, Spring 2021 had an unusually large percentage of aerospace engineering majors, and there is a 36% spread in percentage of students who used the space for capstone. For both schools, there is considerable variation between year in school and number of credit hours. These differences should be kept in mind when examining the data.

Table 15: Demographic Overview by Semester, School A

Category	Demographic	Spring 2021 N = 178	Spring 2022 N = 77	Spring 2023 N = 74	X ²	p
Gender	Male	66%	65%	64%	0.186	0.911
	Female	32%	27%	26%	1.249	0.536
	Other	0%	0%	0%	-	-
	Prefer Not to Disclose	2%	8%	11%	10.292	0.006*
Ethnicity	Hispanic	22%	23%	18%	0.853	0.653
	Non-Hispanic	74%	70%	73%	0.330	0.848
	Prefer Not to Disclose	4%	4%	8%	1.724	0.422
Race	White / Caucasian	67%	61%	59%	1.857	0.395
	Black or African American	2%	0%	1%	1.286	0.526
	American Indian or Alaskan Native	2%	3%	0%	1.810	0.404
	Native Hawaiian/Other Pacific Islander	0%	0%	0%	-	-
	Middle Eastern	2%	1%	4%	1.263	0.532
	Asian	21%	29%	30%	3.098	0.212
	Other	0%	3%	3%	4.777	0.092
	Prefer Not to Disclose	6%	8%	8%	0.398	0.819
Major	Aerospace Engineering	4%	4%	8%	1.724	0.422
	Biomedical Engineering	5%	5%	1%	1.979	0.372
	Chemical Engineering	1%	0%	0%	0.851	0.653
	Computer Engineering	2%	1%	3%	0.384	0.825
	Electrical Engineering	10%	12%	3%	4.452	0.108
	Industrial Engineering	13%	0%	3%	16.041	<0.001*
	Material Science & Engineering	1%	0%	3%	2.322	0.313
	Mechanical Engineering	51%	73%	66%	12.847	0.002*
	Nuclear Engineering	0%	0%	0%	-	-
	Other Major	13%	5%	14%	3.975	0.137
Class	Used Makerspace for a Class This Semester	84%	60%	74%	18.084	<0.001*
	Used Makerspace for Capstone This Semester	26%	44%	30%	8.499	0.014*
	Used Makerspace for Non-Capstone Class This Semester	60%	22%	68%	39.463	<0.001*
Studied	Studied in the Makerspace This Semester	5%	22%	36%	18.668	<0.001*
First Gen	First Generation College Student	20%	16%	14%	1.911	0.385
	Not a First-Generation College Student	79%	83%	74%	1.768	0.413
Transfer	Transfer Student	12%	6%	18%	4.430	0.109
Class Level	Freshman (By Credit Hour)	1%	4%	5%	6.078	0.048*
	Sophomore (By Credit Hour)	11%	8%	9%	0.516	0.773
	Junior (By Credit Hour)	24%	9%	7%	14.732	<0.001*
	Senior (By Credit Hour)	65%	77%	77%	5.831	0.054
Year at School	1st Year Students (No Transfers)	2%	0%	20%	37.364	<0.001*
	2nd Year Students (No Transfers)	21%	22%	11%	4.088	0.129
	3rd Year Students (No Transfers)	26%	13%	5%	16.500	<0.001*
	4th Year Students (No Transfers)	30%	52%	32%	11.402	0.003*
	5th Year Students (No Transfers)	8%	5%	8%	0.660	0.719

*Denotes statistically significant difference

Table 16: Demographic Overview by Semester, School B

Category	Demographic	Spring 2021 N = 94	Spring 2022 N = 95	Spring 2023 N = 84	X ²	p
Gender	Man	57%	56%	64%	1.468	0.480
	Woman	34%	40%	29%	2.589	0.274
	Other	2%	0%	1%	1.977	0.372
	Prefer Not to Disclose	6%	4%	6%	0.478	0.787
Ethnicity	Hispanic	11%	16%	15%	1.292	0.524
	Non-Hispanic	84%	80%	81%	0.560	0.756
	Prefer Not to Disclose	5%	4%	4%	0.334	0.846
Race	White / Caucasian	49%	58%	45%	3.082	0.214
	Black or African American	1%	5%	5%	2.776	0.250
	American Indian or Alaskan Native	1%	0%	0%	1.911	0.385
	Native Hawaiian or Other Pacific Islander	0%	0%	0%	-	-
	Middle Eastern	2%	2%	1%	0.277	0.870
	Asian	46%	29%	42%	5.678	0.058
	Other	1%	4%	7%	4.252	0.119
	Prefer Not to Disclose	4%	4%	4%	0.066	0.968
Major	Aerospace Engineering	23%	4%	2%	27.087	<0.001*
	Biomedical Engineering	0%	6%	5%	5.756	0.056
	Chemical Engineering	0%	1%	1%	1.070	0.586
	Computer Engineering	0%	1%	4%	4.091	0.129
	Electrical Engineering	0%	3%	2%	2.824	0.244
	Industrial Engineering	0%	1%	0%	1.881	0.391
	Material Science and Engineering	0%	0%	0%	-	-
	Mechanical Engineering	70%	66%	70%	0.441	0.802
	Nuclear Engineering	0%	0%	0%	-	-
	Other	6%	17%	14%	5.114	0.078
Class	Used Makerspace for a Class This Semester	68%	76%	71%	1.393	0.498
	Used Makerspace for Capstone This Semester	17%	53%	46%	28.568	<0.001*
	Used Makerspace for Non-Capstone Class This Semester	52%	28%	37%	11.409	0.003*
Studied	Studied in the Makerspace This Semester	19%	24%	38%	1.052	0.591
Volunteer	Student Volunteer This Semester	9%	15%	24%	8.023	0.018*
First Gen	First Generation College Student	16%	21%	17%	0.968	0.616
Transfer	Transfer Student	12%	13%	17%	1.039	0.595
Class Level	Freshman (By Credit Hours)	7%	2%	5%	2.973	0.226
	Sophomore (By Credit Hours)	34%	18%	14%	11.641	0.003*
	Junior (By Credit Hours)	24%	7%	15%	10.418	0.005*
	Senior (By Credit Hours)	33%	72%	64%	31.923	<0.001*
Year at School	1st Year Students (No Transfers)	36%	4%	11%	37.461	<0.001*
	2nd Year Students (No Transfers)	26%	12%	27%	8.228	0.016*
	3rd Year Students (No Transfers)	5%	6%	8%	0.673	0.714
	4th Year Students (No Transfers)	10%	37%	13%	25.587	<0.001*
	5th Year Students (No Transfers)	10%	13%	20%	4.412	0.110

*Denotes significantly significant difference

5.2 Makerspace Usage During COVID

5.2.1 Types of Makerspace Use

Figure 13 and Figure 14 show student motivations for using the makerspaces. At School A, at least 70% of students used the space for class each semester and between 5% and 20% of students used the space for personal projects. Given that the purpose of School A's makerspace is to support undergraduate engineering courses, and personal projects are not permitted, this is no surprise. However, it is clear some students are using the space for personal projects anyway and this is an important need. At School B, between 63% and 74% of students used the space for class each semester and between 36% and 61% of students use the space for personal projects. The gap between class and personal project usage continues to decrease at School B, moving from 27% in Spring 2021 to 16% in Spring 2022 and finally to 8% in Spring 2023. This is likely due to more students using the space for personal projects as COVID-19 restrictions subsided.

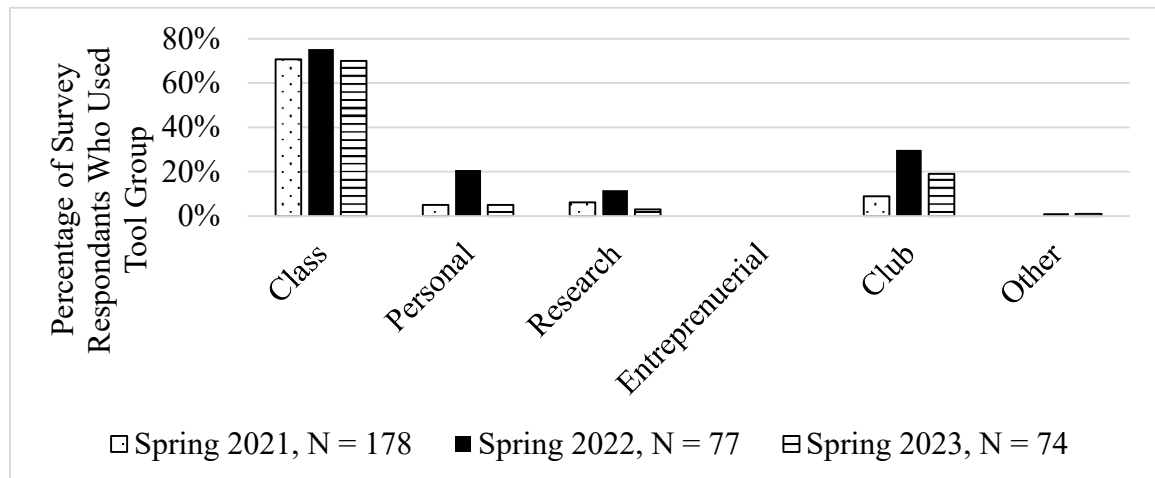


Figure 13: Usage Type by Semester, School A

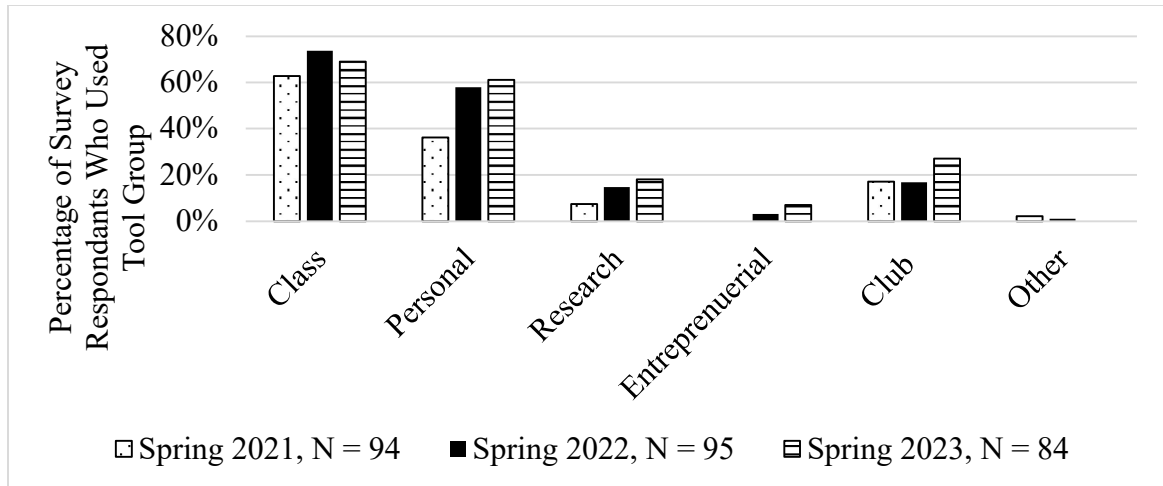


Figure 14: Usage Type by Semester, School B

5.2.2 Duration of Makerspace Use

Makerspace usage was quantified in multiple ways. First, the number of hours students spent in a makerspace in a normal week was compared across semesters and is presented in Figure 15 and Figure 16. At both schools, usage was very low in Spring 2021 with 65% of students at School A and 46% of students at School B not using the space at all or using it less than one hour in an average week. In Spring 2022 and Spring 2023 usage increases drastically, with the most common number of hours being 3-5 hours per week. Despite many students still using the makerspaces during COVID-19, most limited the amount of their exposure within the space. This may be due to restrictions that the university put in place or students' fear of getting sick.

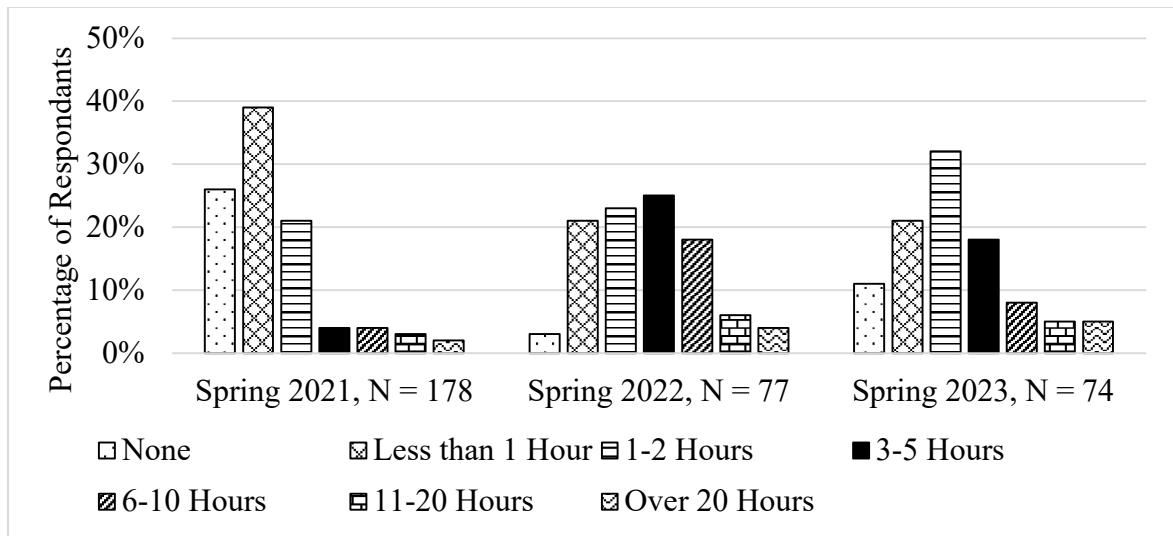


Figure 15: Hours Spent in School A's Makerspace per Week

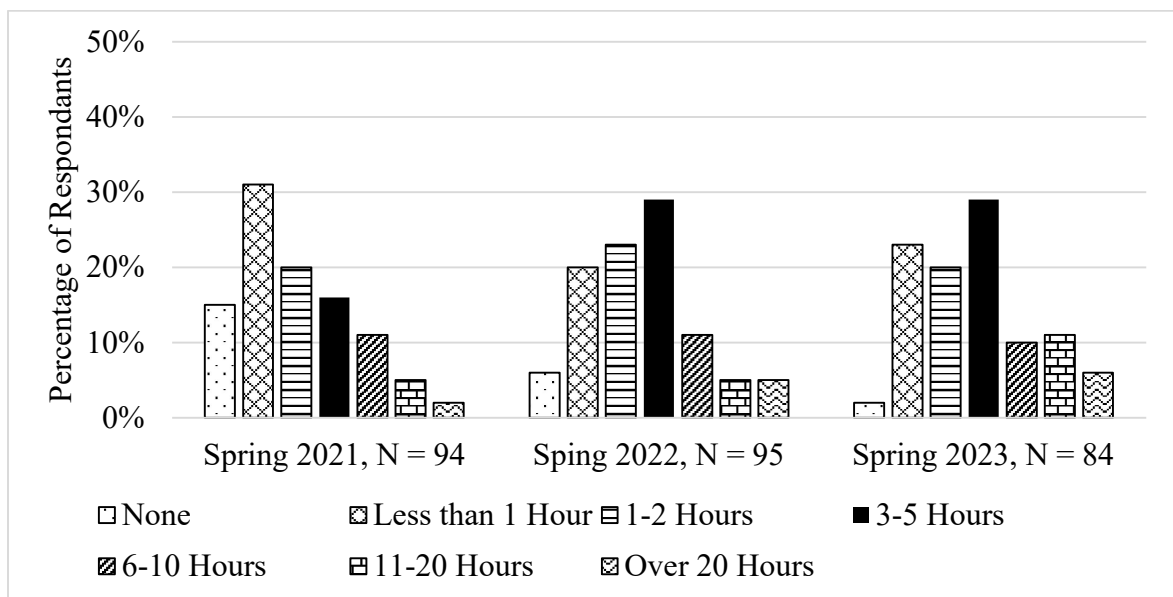


Figure 16: Hours Spent in School B's Makerspace per Week

5.2.3 Frequency of Makerspace Use

Another way to measure makerspace usage is by the frequency of visits. Figure 17 and Figure 18 show this analysis at each school, compared across the three semesters. At School A, the most common frequency varies by semester. Visit frequency is somewhat

evenly distributed in Spring 2021, is most commonly 2-3 times a week in Spring 2022 and decreases to once a week in Spring 2023. The frequency doesn't change as much at School B, with the most common frequency being 2-3 times a week across all three semesters.

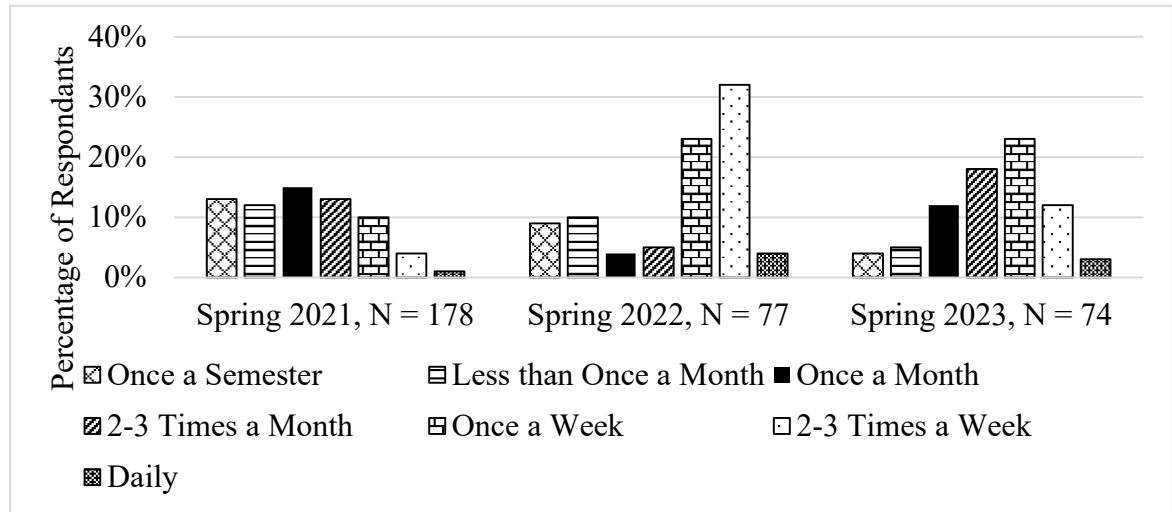


Figure 17: Frequency of Student Visits at School A's Makerspace

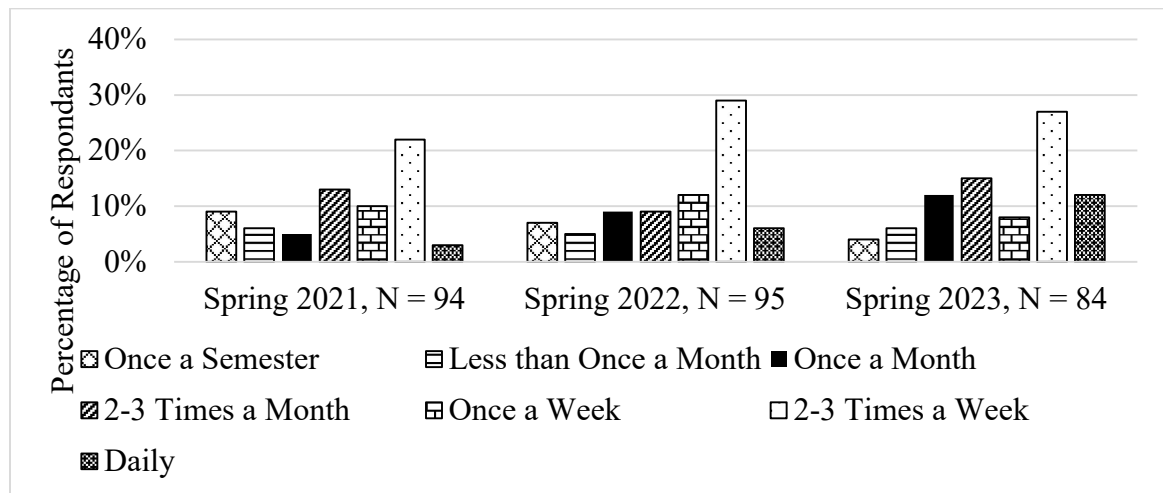


Figure 18: Frequency of Student Visits at School B's Makerspace

5.2.4 Tool Usage During COVID

Figure 19 shows the mean and median number of tools used by students at each makerspace. The specific tool responses were used to generate this plot, and any tool that was not comparable across the three semesters was removed from the count. There was a total of 73 tools on the School A survey and 62 tools on the School B survey. Again, it is seen that usage increased when COVID restrictions were removed, and that usage is in general higher at School B.

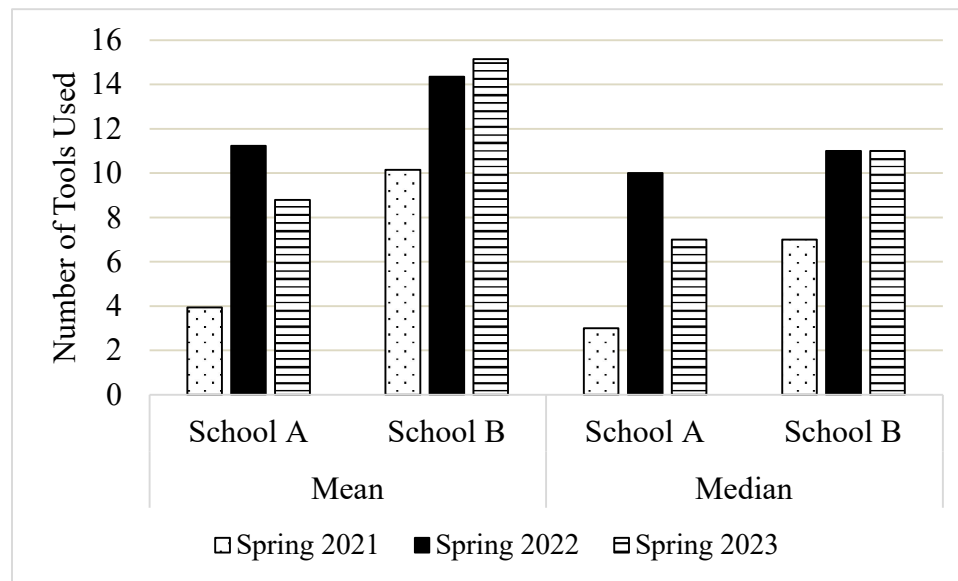


Figure 19: Mean and Median Number of Tools Used by Students at School A and School B

Figure 20 and Figure 21 show the percentage of students who used general tools at each university, respectively. Like prior figures, Spring 2021 had decreased usage for both schools. At School A, percentage tool usage was highest in Spring 2022 for most tool categories except for 3D printers and metal tools, which are both tools that are heavily used for classes at this school. At School B, laser cutter usage decreased in Spring 2023 due to

several of the laser cutters undergoing maintenance. Otherwise, Spring 2021 had the lower usage percentage for all other tools.

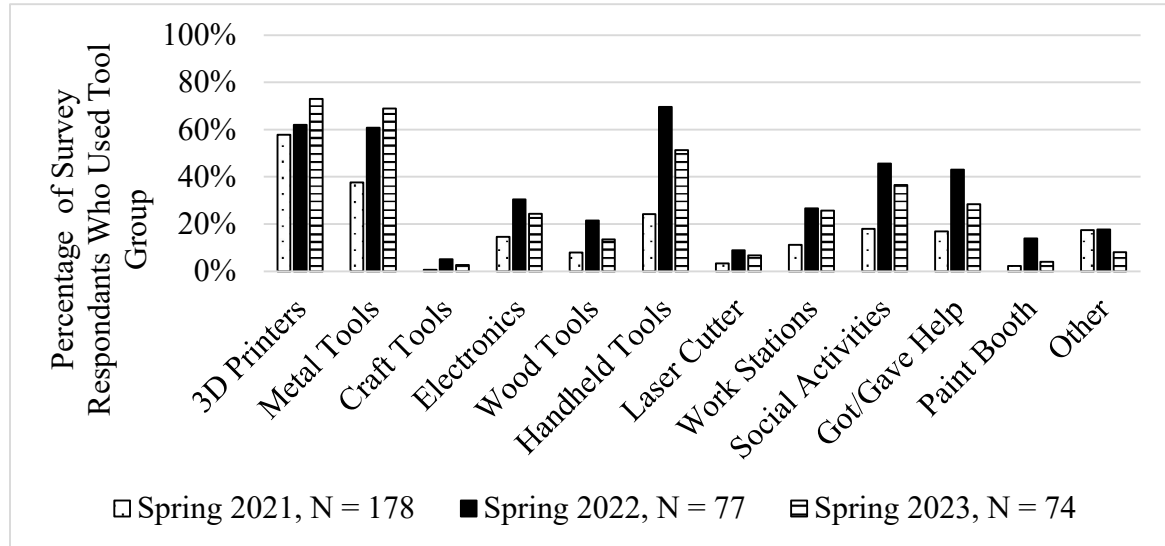


Figure 20: General Tool Usage Across Semesters, School A

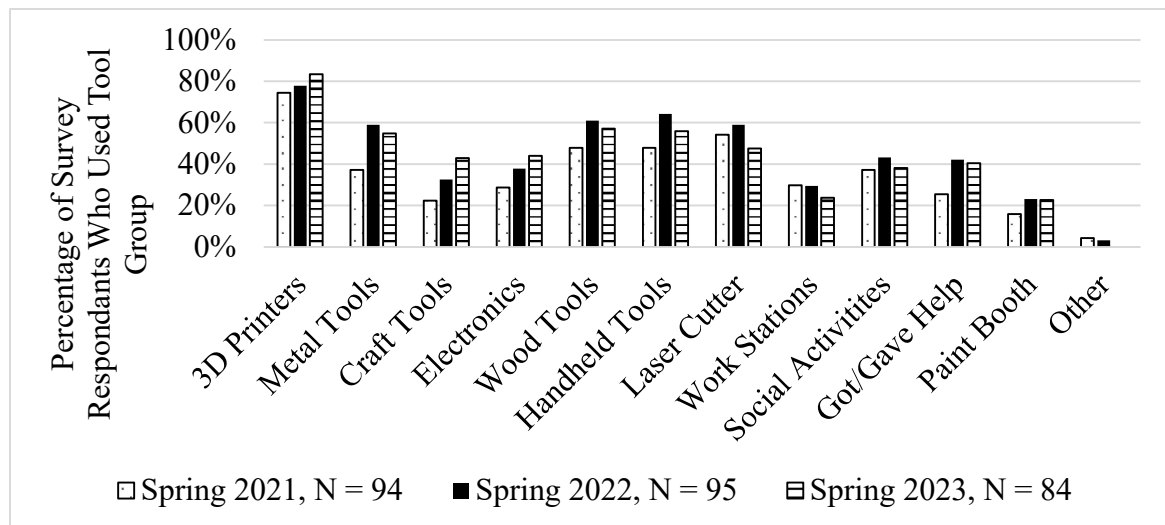


Figure 21: General Tool Usage Across Semesters, School B

Figure 22 shows the percentage difference in tool usage between Spring 2021 and Spring 2022 for each school. At both schools, the 3D printer and the laser cutter had very

small changes in percentage usage across the semesters. On the other hand, metal tools and giving/receiving help had large changes for both schools. Metal tools may be due to differences in professors assigning projects during COVID-19. At School B, very little change is seen between workstations and social activities. This is likely attributed to the space being open for students to study and work on projects despite the pandemic. With many other facilities around campus being closed, and students tired of studying in their dorm room, the makerspace presented a welcoming environment.

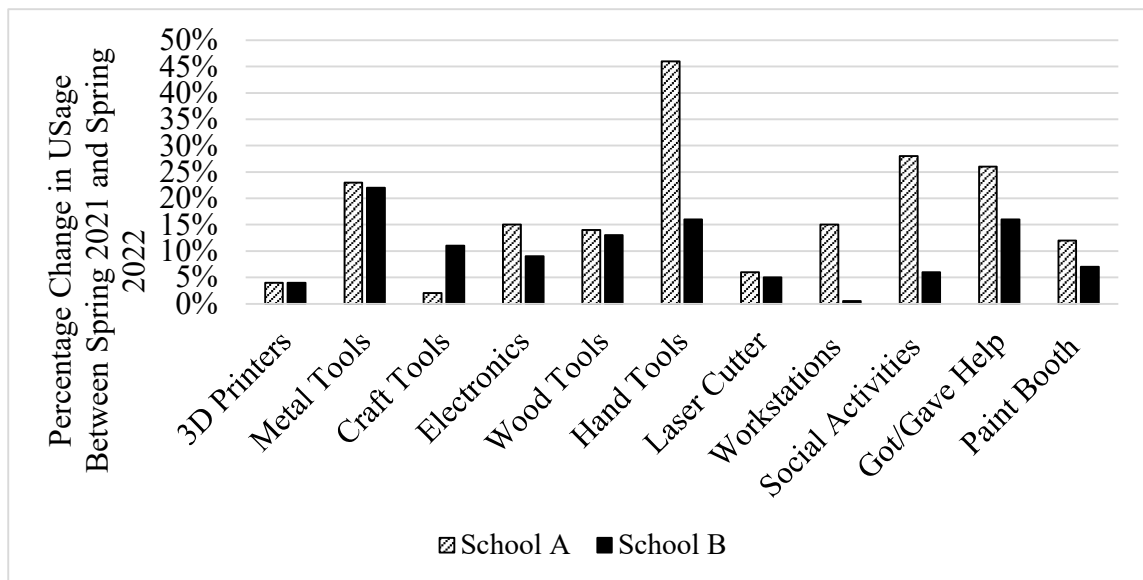


Figure 22: Change in Percentage Usage of Tool Groups Between Spring 2021 and Spring 2022

5.3 Motivations for Using the Space Less

Finally, an open-ended question on the survey asked, “If you used the space less this semester compared to previous semesters, why?” The answers to this question were coded based on five categories: Remote Learning, COVID Restrictions, Other Restrictions or Policies, No Need, and Other. The “Remote Learning” category was used when students

mentioned being enrolled in online classes or not being physically present on campus. The “COVID Restrictions” category was used for any other response that mentioned COVID-19. Some responses were assigned more than one applicable category. Two raters independently categorized a subset of the answers and then discussed the assigned categories. The percentage agreement of this preliminary subset was 63%. Following the discussion and alignment, both raters categorized the remaining responses, and the percentage agreement was recalculated to be 85%. Most of the ratings that did not align were the result of one rater assigning two categories and the other only assigning one category.

The categorized responses are shown in Figure 23 and Figure 24. Remote Learning and COVID-19 related restrictions were very popular answers during Spring 2021, but then hardly anyone gave these responses from Spring 2022 onward. At School A, the most common answer in later semesters was “no need”. This reflects the fact that the space gets used primarily for class and if students are not taking a class that requires the space, their usage declines. At School B, the most common answer was “other” where students often mentioned not having enough time to work on projects, or the open hours not aligning with their class schedules. Finally, a handful of responses were categorized into the “Other Restrictions/Policies” category. These students mentioned frustrating aspects of working in the makerspace such as having to reserve tools well in advance, unfriendly staff, and unclear entrance policies.

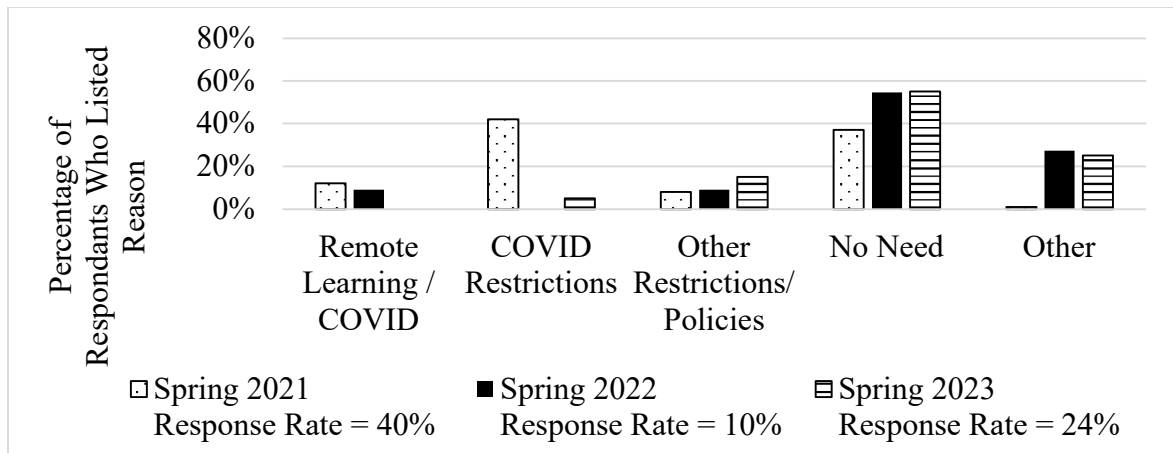


Figure 23: Motivations for Using the Space Less, School A

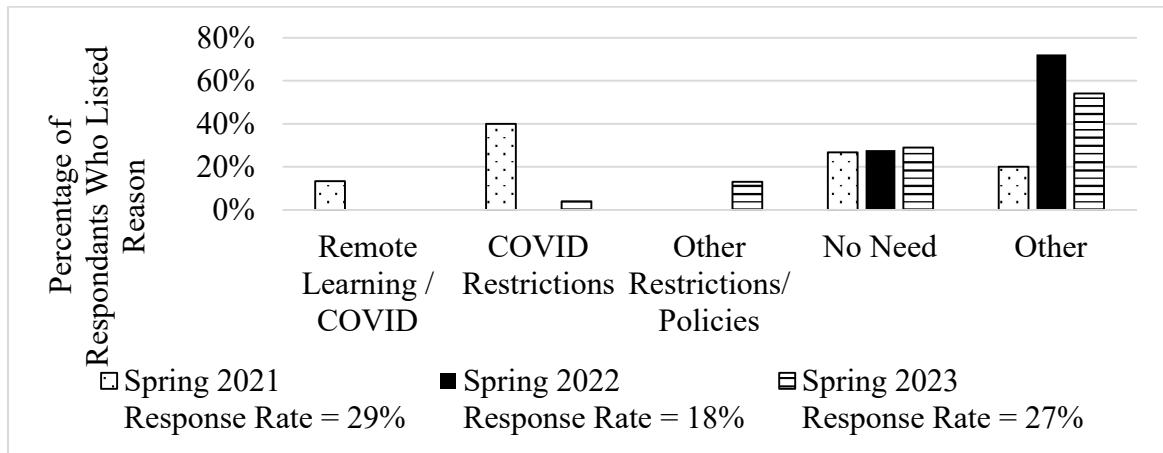


Figure 24: Motivations for Using the Space Less, School B

5.4 Discussion

Both schools faced substantial changes in makerspace usage during the Spring 2021 semester when COVID restrictions were at their greatest. At School A, roughly the same percentage of students reported using the space for class each semester, but frequency and duration of makerspace use were far lower in Spring 2021, which likely represents the ways that professors and makerspace staff limited groupwork and interaction within the space. At School B there was little change to class usage, but personal project usage dropped

substantially. While students still reported visiting the space at similar frequencies, they spent less time inside. Tools such as the 3D printer and laser cutter were less effected by the restrictions than other tools such as metal and handheld tools.

While both makerspaces were hurt by the restrictions, School B usage declined much less than School A usage. It is speculated that this is due to the student-run, less restricted atmosphere of School B's makerspace. Factors such as allowing personal projects and not closing workspaces/study areas may prove very helpful in overcoming disruptions.

Despite these changes to the makerspace during heightened restrictions, makerspace staff should be encouraged by the quick recovery. Only one year later, tool usage percentages all increased. Further data collection in 2023 only revealed slight improvement at the two-year mark.

When a person desires to maintain their health, doctors recommend they are intentional in their eating, sleeping, and exercising patterns and come in for regular "well-visits" to check for underlying issues and address any concerns. A similar principle can be applied to academic makerspaces. Instead of waiting until the space is noticeably struggling, routine check-ups and maintaining healthy habits are beneficial to maintaining long term makerspace health and identifying problems before they fully mature. Some problems arise gradually over time, others are nearly instantaneous such as the COVID induced shutdown. In either case, careful planning can minimize effects to makerspaces.

One complaint of multiple students was the cryptic restrictions in place during COVID. While a large percentage of students mentioned COVID restrictions caused them to use the space less, some elaborated and explained that the restrictions were hard to

comprehend. One student stated “COVID protocols seemed harder to understand and adapt to” while another said they used the space less because of the “confusing website and training”. This concern was also noted by administration at other makerspaces [27]. During a scenario such as COVID, makerspace staff have little say over restrictions in place. Even so, it is imperative that they make it clear to users what the expectations are for entrance or membership and that there are no implicit rules [25, 44]. During a period when entrance requirements are changing rapidly, it becomes increasingly important that new guidelines are conveyed. This leaves all involved feeling safe, and as though they belong.

Another consideration is the use of virtual technology such as video-based training to convey information in a safe yet clear and inviting way when staff instruction is limited. Makerspaces would be wise to invest time and energy into creating such content now so that it is available in the case of any future such scenarios and lack of knowledge does not provide an additional barrier to entry on top of the restrictions in place [41, 42].

Finally, staff should pay attention to tools that change the most or least in percentage usage and use this to the space’s advantage when recovering from a decline or integrating makerspace use into coursework. Qualitative and open-ended questions can be used to better understand the *why* behind makerspaces changes as well.

CHAPTER 6. PILOT STUDY: INVOLVEMENT, CONTINUANCE, AND SENSE OF BELONGING IN ACADEMIC MAKERSPACES

6.1 Motivation and Background

Data collected in Fall 2020, Spring 2021, and Spring 2022 indicated that not all groups of students are equally involved or comfortable in academic makerspaces [21, 72]. The results presented in Chapter 4 depict the same thing, with underrepresented student groups such as women having lower percentage usage of most tools. Similar discrepancies have been noted and studied in literature as discussed in Chapter 2.3.

Two steps were taken in Fall 2022 and Spring 2023 to better understand the cause of this discrepancy and then address it. First, a series of Likert style questions on belonging were added to the end of the semester surveys [47, 48]. Sense of belonging is often correlated with student's motivation to participate in academic makerspaces and other entities [47, 48, 53]. The goal of these questions was to gain a better understanding of student's sense of belonging or lack thereof.

Secondly, a series of experiments were run to see if workshops could be used to increase the tool usage and sense of belonging among underrepresented groups and what method of workshop would be most effective. This was done by offering hands-on and tour-based workshops to specific populations of students and then analyzing how their tool usage and sense of belonging changed after the workshop. Preliminary results from this study are presented, but given the small sample size, no conclusions can yet be drawn.

6.2 Belonging Questions

6.2.1 Methods

A series of 13 questions on sense of belonging, developed by Nadelson, et. al. [47, 48], were listed at the conclusion of the end of semester survey in Fall 2022 and Spring 2023. Whenever the word “makerspace” appeared, the name of the main engineering makerspace at School A or the makerspace located in the mechanical engineering building at School B was listed, depending on the school. An example question read “I feel comfortable in the makerspace”. The questions were presented on a 5-point Likert scale where students read a series of statements and choose the extent to which they agreed or disagreed. The first 10 questions were positively phrased, while the last 3 questions were negatively phrased. The scale for the negatively worded questions was reversed for the analysis, as shown in Table 17, and the converse statements are listed in the results. Due to the Likert style questions and the non-normality of the results, the data were analyzed using the Mann Whitney U statistical test, a non-parametric alternative to the independent samples t-test.

Table 17: Likert Scale for Positively and Negatively Worded Questions

Positively Worded	Likert Scale	Negatively Worded
1	Strongly Disagree	5
2	Disagree	4
3	Neutral	3
4	Agree	2
5	Strongly Agree	1

6.2.2 Results

Table 18 presents the mean and standard deviation scores for each question as well as the results of a Mann Whitney U Test comparing the two schools. The only questions with statistical difference between schools were the statements “I feel comfortable in engineering classrooms” for which students scored higher at School A and “I’d like the chance to interact with the student workers in the makerspace more often” for which students scored higher at School B. The four highest scoring statements for both schools were “I feel comfortable in engineering classrooms”, “I feel like I can really trust the student workers in the makerspace”, “I feel comfortable in the makerspace”, and “I enjoy working on group projects in the makerspace” each of which had an average between Agree and Strongly Agree. Most of the other statements had mean scores between Neutral and Agree. The lowest scoring statement for both schools was “I prefer to work with others in the makerspace” which scored between Disagree and Neutral.

Table 18: Mean and Standard Deviation Values for Belonging Questions

Survey Question	School A, N = 283		School B, N = 153		School Comparison			
	Mean	Std	Mean	Std	Mean Rank (A)	Mean Rank (B)	Z	p-value
I feel comfortable in the makerspace.	4.05	1.03	4.10	0.99	214.02	218.63	-0.39	0.696
I feel like I can really trust the student workers in the makerspace.	4.27	0.92	4.20	0.87	226.14	211.26	-1.289	0.197
I feel comfortable in engineering classrooms.	4.37	0.83	4.22	0.84	216.82	194.78	-2.003	0.045*
I feel valued in the makerspace.	3.58	1.12	3.74	1.00	201.69	216.85	-1.271	0.204
I feel valued in engineering classrooms.	3.91	0.93	3.94	0.93	198.86	202.29	-0.303	0.762
I enjoy working on group projects in the makerspace.	4.08	1.07	3.96	0.98	207.92	188.58	-1.741	0.082
I'd like the chance to interact with the student workers in the makerspace more often.	3.61	1.09	3.92	1.01	192.21	226.17	-2.848	0.004*
I have made friends through my work in the makerspace.	3.47	1.22	3.36	1.25	207.59	197.31	-0.875	0.382
I'd like a chance to interact with other students in the makerspace more often.	3.75	0.98	3.79	0.96	208.39	212.41	-0.34	0.734
I feel like I can really trust fellow students in the makerspace.	3.92	0.91	3.93	0.92	212.95	215.34	-0.205	0.838
I feel respected by my peers in the makerspace.	3.85	1.07	3.90	1.12	205.96	215.32	-0.798	0.425
I prefer to work with others in the makerspace.	2.55	1.06	2.74	1.15	200.52	218.99	-1.533	0.125
I feel connected to fellow students in the makerspace.	3.63	1.12	3.50	1.11	222.76	207.62	-1.267	0.205

Statistics in Table 19 compare results for men and women students. There were a few students at each school who selected other genders or denoted that they preferred not to answer, however the sample size was not large enough to compare these groups. At School A, it was found that women have a higher sense of value in engineering classrooms ($Z = -2.083$, $p = 0.037^*$), feel more respected by their peers in the makerspace ($Z = -2.262$, 0.024^*), and feel more connected to fellow students in the makerspace (-2.734 , 0.006^*). These results are quite surprising given the opposite results of many other studies that have been conducted [23, 24, 42, 45]. At School B, it was found that men reported a statically higher sense of comfort in the makerspace ($Z = -3.264$, $p = 0.001^*$) and in engineering

classrooms ($Z = -3.018$, $p = 0.003^*$). Additionally, they felt statistically more valued in their engineering courses ($Z = -2.865$, $p = 0.004^*$).

Table 19: Mann Whitney U Test Results for Men (M) vs Women (W)

Survey Question	School A, n = 100, n = 42				School B, n = 164, n = 84			
	Mean (M)	Mean (W)	Z	p-value	Mean (M)	Mean (W)	Z	p-value
I feel comfortable in the makerspace.	4.08	4.19	-0.302	0.763	4.22	3.87	-3.264	0.001*
I feel like I can really trust the student workers in the makerspace.	4.23	4.50	-1.557	0.119	4.17	4.20	-0.036	0.971
I feel comfortable in engineering classrooms.	4.35	4.48	-0.36	0.719	4.39	4.00	-3.018	0.003*
I feel valued in the makerspace.	3.56	3.79	-0.997	0.319	3.81	3.63	-1.399	0.162
I feel valued in engineering classrooms.	3.80	4.17	-2.083	0.037*	4.11	3.70	-2.865	0.004*
I enjoy working on group projects in the makerspace.	4.07	4.21	-1.216	0.224	4.04	3.81	-1.491	0.136
I'd like the chance to interact with the student workers in the makerspace more often.	3.62	3.64	-0.286	0.775	3.86	4.01	-0.957	0.338
I have made friends through my work in the makerspace.	3.44	3.65	-0.986	0.324	3.45	3.15	-1.573	0.116
I'd like a chance to interact with other students in the makerspace more often.	3.77	3.73	-0.471	0.638	3.81	3.78	-0.258	0.797
I feel like I can really trust fellow students in the makerspace.	3.92	3.98	-0.283	0.777	3.91	4.02	-0.440	0.660
I feel respected by my peers in the makerspace.	3.79	4.10	-2.262	0.024*	3.89	3.94	-0.268	0.789
I prefer to work with others in the makerspace.	2.48	2.75	-1.013	0.311	2.62	2.88	-1.567	0.117
I feel connected to fellow students in the makerspace.	3.52	4.10	-2.734	0.006*	3.56	3.44	-0.969	0.332

Sense of belonging was also evaluated based on major. A summary of the results for mechanical engineering students vs non-mechanical engineering students is shown in Table 20. At School A, non-mechanical engineering majors report statistically higher scores for the statements “I have made friends through my work in the makerspace” ($Z = -2.602$, $p = 0.009^*$), “I feel like I can really trust fellow students in the makerspace” ($Z = -2.873$, $p = 0.004^*$), and “I feel respected by my peers in the makerspace” ($Z = -2.214$, $p = 0.027^*$) all of which deal with their interactions with other students. At School B,

Mechanical engineering students reported a statistically higher feeling of comfort in the makerspace ($Z = -2.067$, $p = 0.039^*$), but none of the other results were statistically significant, indicating that major does not play a large roll in sense of belonging at this makerspace.

Table 20: Mann Whitney U Test Results for Mechanical Engineering Majors (ME) vs Non-Mechanical Engineering Majors (Not ME)

Survey Question	School A, n = 88, n = 65				School B, n = 134, n = 149			
	Mean (ME)	Mean (Not ME)	Z	p-value	Mean (ME)	Mean (Not ME)	Z	p-value
I feel comfortable in the makerspace.	3.91	4.25	-1.832	0.067	4.22	3.99	-2.067	0.039*
I feel like I can really trust the student workers in the makerspace.	4.22	4.34	-0.172	0.864	4.09	4.29	-1.580	0.114
I feel comfortable in engineering classrooms.	4.38	4.35	-0.378	0.705	4.31	4.12	-1.779	0.075
I feel valued in the makerspace.	3.55	3.62	-0.331	0.741	3.73	3.75	-0.039	0.969
I feel valued in engineering classrooms.	3.99	3.80	-1.160	0.246	3.96	3.91	-0.405	0.686
I enjoy working on group projects in the makerspace.	3.99	4.21	-0.933	0.351	3.97	3.96	-0.388	0.698
I'd like the chance to interact with the student workers in the makerspace more often.	3.72	3.46	-1.479	0.139	3.88	3.95	-0.036	0.971
I have made friends through my work in the makerspace.	3.25	3.78	-2.602	0.009*	3.44	3.29	-0.918	0.359
I'd like a chance to interact with other students in the makerspace more often.	3.72	3.79	-0.451	0.652	3.76	3.82	-0.403	0.687
I feel like I can really trust fellow students in the makerspace.	3.74	4.17	-2.873	0.004*	3.87	3.99	-1.080	0.280
I feel respected by my peers in the makerspace.	3.71	4.03	-2.214	0.027*	3.77	4.03	-1.785	0.074
I prefer to work with others in the makerspace.	2.52	2.59	-0.392	0.695	2.69	2.78	-0.587	0.557
I feel connected to fellow students in the makerspace.	3.54	3.75	-1.137	0.256	3.49	3.51	-0.020	0.984

Next, results from students who indicated that they studied in the space were compared to results of students who indicated that they did not study in the space. These statistics are found in Table 21. At School A, those that studied in the space preferred working with others in the makerspace statistically more than those who did not study in

the space ($Z = 91.34$, $p = 0.014^*$). At School B, those that studied scored statistically higher in sense of comfort in the makerspace ($Z = -3.018$, $p = 0.003^*$). Additionally, their relations with other students in the space were reported as statistically higher in categories such as making friends through the makerspace ($Z = -4.164$, $p < 0.001^*$), trust of other students ($Z = -2.932$, $p = 0.003^*$), feeling connected with fellow students ($Z = -2.25$, $p = 0.024^*$), and wanting to interact with other students in the makerspace more often ($Z = -2.273$, $p = 0.023^*$).

Table 21: Mann Whitney U Test Results for Students Who Study in the Space (Y) vs Those Who Do Not (N)

Survey Question	School A, n = 33, n = 120				School B, n = 64, n = 219			
	Mean (Y)	Mean (N)	Z	p-value	Mean (Y)	Mean (N)	Z	p-value
I feel comfortable in the makerspace.	4.03	4.06	-0.636	0.525	4.44	4.00	-3.018	0.003*
I feel like I can really trust the student workers in the makerspace.	4.34	4.25	-0.178	0.858	4.27	4.18	-0.532	0.595
I feel comfortable in engineering classrooms.	4.38	4.37	-0.066	0.947	4.29	4.20	-0.945	0.344
I feel valued in the makerspace.	3.73	3.53	-0.670	0.503	3.90	3.69	-1.555	0.120
I feel valued in engineering classrooms.	3.97	3.89	-0.081	0.936	3.97	3.93	-0.517	0.605
I enjoy working on group projects in the makerspace.	4.03	4.09	-0.648	0.517	4.19	3.89	-1.747	0.081
I'd like the chance to interact with the student workers in the makerspace more often.	3.64	3.60	-0.060	0.952	3.98	3.90	-0.374	0.708
I have made friends through my work in the makerspace.	3.66	3.41	-1.099	0.272	3.93	3.18	-4.164	<.001*
I'd like a chance to interact with other students in the makerspace more often.	3.88	3.72	-0.801	0.423	4.05	3.72	-2.273	0.023*
I feel like I can really trust fellow students in the makerspace.	3.82	3.95	-0.996	0.319	4.22	3.85	-2.932	0.003*
I feel respected by my peers in the makerspace.	3.97	3.81	-0.154	0.877	4.00	3.88	-1.251	0.211
I prefer to work with others in the makerspace.	2.94	2.45	-2.468	0.014*	2.94	2.68	-1.485	0.138
I feel connected to fellow students in the makerspace.	3.64	3.63	-0.054	0.957	3.77	3.41	-2.250	0.024*

Finally, Table 22 shows the results of students who were taking a class that required makerspace usage vs students who were not taking such as a class. The results imply that

at School B, those who used the makerspace for class enjoy working with others in the space ($Z = -2.289$, $p = 0.022^*$) statistically more than students who did not use the space for class. There are no statistically significant results at School A, likely because most students at this school are using the space for class and the non-class user sample size is small.

Table 22: Mann Whitney U Test Results for Students Who Took a Class That Required Use of the Space (Y) vs Those Who Did Not (N)

Survey Question	School A, n = 126, n = 27				School B, n = 159, n = 124			
	Mean (Y)	Mean (N)	Z	p-value	Mean (Y)	Mean (N)	Z	p-value
I feel comfortable in the makerspace.	4.04	4.11	-0.605	0.545	4.15	4.03	-1.186	0.236
I feel like I can really trust the student workers in the makerspace.	4.27	4.26	-0.214	0.830	4.15	4.25	-0.663	0.507
I feel comfortable in engineering classrooms.	4.36	4.41	-0.255	0.799	4.27	4.15	-1.224	0.221
I feel valued in the makerspace.	3.56	3.67	-0.304	0.761	3.72	3.76	-0.182	0.856
I feel valued in engineering classrooms.	3.87	4.07	-0.924	0.355	3.99	3.86	-1.078	0.281
I enjoy working on group projects in the makerspace.	4.03	4.32	-0.958	0.338	4.04	3.84	-1.555	0.120
I'd like the chance to interact with the student workers in the makerspace more often.	3.63	3.52	-0.540	0.589	3.90	3.93	-0.131	0.895
I have made friends through my work in the makerspace.	3.43	3.64	-0.763	0.445	3.47	3.21	-1.697	0.090
I'd like a chance to interact with other students in the makerspace more often.	3.71	3.92	-0.959	0.338	3.82	3.76	-0.649	0.516
I feel like I can really trust fellow students in the makerspace.	3.86	4.19	-1.526	0.127	3.89	3.98	-0.779	0.436
I feel respected by my peers in the makerspace.	3.80	4.08	-1.345	0.179	3.80	4.04	-1.348	0.178
I prefer to work with others in the makerspace.	2.62	2.23	-1.730	0.084	2.60	2.92	-2.289	0.022*
I feel connected to fellow students in the makerspace.	3.60	3.78	-0.437	0.662	3.42	3.59	-1.233	0.217

6.2.3 Discussion

Gender comparison at School B showed that women students reported a lower sense of comfort both in makerspaces and the engineering classroom. This is consistent with prior work [42, 45, 48] and careful attention should be given to address this discrepancy. Tomko *et. al.* suggests that apprenticeship, catalyst activities, and positive women staff members are effective means to draw more women into makerspaces [24]. Other work emphasizes the need to make sure makerspaces appear inviting and supportive of beginners given the lack of confidence many women experience when first visiting a campus makerspace [42, 56]. At School A, women students reported a higher sense of value in engineering classrooms as well as a higher level of respect and connection with peers. While this is unusual, it may be the result of the makerspace being used primarily for class purposes, with adequate instruction given for any task the students are expected to complete or it may be something happening at this school since value in engineering was also higher.

Comparison by major showed that at School A, non-mechanical engineering majors report higher levels of friendship and trust/respect with peers. While the cause of this can only be speculated, it is possible that this is the result of the types of projects non-mechanical engineering students are expected to complete. At School B, there is a higher sense of comfort in makerspaces for mechanical engineering students, but no other significant results. This is both surprising and encouraging given the makerspace's prominent location in a large mechanical engineering building and several mechanical engineering classes that ask students to use the space. One possible way to resolve the remaining difference in comfort is for professors of other majors, specifically other

engineering disciplines, to offer assignments that encourage students to enter the space, especially early in the curriculum.

Socializing inside the makerspace was found to be highly related to students' sense of belonging and positive relations with other students in the space, especially at School B. However, this correlation does not necessarily indicate a causation. It is unclear whether students who socialize in the space through activities such as hanging out, studying, or meeting with a group improve their sense of belonging or students who feel as though they belong tend to socialize more in the space. Either way, university makerspace leadership should pay close attention to the quantity and location of their study and hang out space and use this correlation to encourage more people to enter and utilize the makerspace.

Class usage was not highly correlated with sense of belonging, though students who used the space for class reported higher enjoyment of working with other people at School B. This suggests that instructors should continue to encourage hands on and makerspace related projects whenever possible as the collaborative environment encourages student teamwork.

6.3 Workshops

6.3.1 Methods

The second part of the experiment consisted of offering workshops to underrepresented student groups on campus. To recruit participants, exec board members from various student organizations were contacted and their groups were invited to participate in a makerspace workshop. If the organization expressed interest in attending a

workshop, a date was selected, and a QR code and link to a sign-up form sent to the exec board to pass along to their members.

For each student group, two different versions of the event were hosted, and students were asked to sign up for either one or the other on the sign-up form. The first version consisted of a hands-on activity while the second consisted of a tour. No indication was given to the students that the sections would be different. At School A, the two versions of each workshop were held a week apart, but at the same time. At School B, they were held on the same day, a half hour apart. The order of the versions was alternated for each group at School B so that the order and time of day did not bias the results. Table 23 outlines the workshops that were hosted each semester.

Table 23: Workshops Offered at School A and School B Each Semester

School A		
	Fall 2022	Spring 2023
Hispanic Engineers Group		X
Women Mechanical Engineers		X
Mechanical Engineers		X
School B		
	Fall 2022	Spring 2023
Black Engineers Group	X	X
Hispanic Engineers Group	X	X
First Generation Students	X	
Women Engineers Group	X	
Latin American Group		X

The hands-on workshop was depth focused. At School B, students were taught how to set up a vector file for use on the laser cutter, and then observed as the workshop host used the machine to cut out an MDF coaster for each participant. Then, they learned how to properly slice and upload a simple 3D printed part to the 3D printing queuing system.

Each student went through the 3D printing process individually, so that they learned the steps and could repeat it for themselves later. The parts were printed for the students after hours and placed in pick up bins outside the space for students to come and pick up. At the end, students received a very brief walk through of the rest of the space. At School A, the hands-on event consisted of the students watching how to properly slice a small 3D printed part, and then physically loading the filament spool and hitting go on the 3D printer. Students came and picked up their parts the following day. They did not learn how to use the laser cutter at School A but did receive a tour of the space.

The tour workshop was breadth focused. Instead of using any of the tools themselves, students were given a detailed tour of the entire makerspace. Each tool group was explained, and an overview given of the tools and materials available for student use. During the tour, students were encouraged to ask questions about the tools and about the space. At the end, students at School B were given the same laser cut MDF coaster, and small 3D printed part that the hands-on workshop participants received. Students at School A did not receive anything after the tour.

At the start of both the hands-on and tour workshops, it was mentioned the workshops were being held in conjunction with a research lab on campus and students could participate by completing an entry survey and an exit survey. It was emphasized that they could attend the workshop regardless of whether they took the surveys. Every student who completed *both* the entry and exit surveys was compensated with a \$5 gift card. The entry survey asked questions about prior makerspace participation and tool usage and resembled the start of the end of semester survey. The sense of belonging questions were also included at the end of the entry survey. The exit survey asked questions about major

and demographics and gave students an opportunity to provide feedback about the event. At the end of the semester, all students who participated in the workshop surveys were invited to complete the end of semester survey. This version of the survey included a few additional questions about which event they attended and whether they picked up their 3D printed part if they were in the hands-on group.

Workshops were hosted at School B in Fall 2022 and at both schools in Spring 2023. The results from the workshops were analyzed in two ways. First, the sense of belonging questions from the workshop entry survey were compared to responses to the sense of belonging questions in the end of semester survey. Secondly, the tools used were analyzed to see if students reported using any new tools in the end of semester survey that they did not list in the workshop entry survey.

6.3.2 Participants

In Fall 2022, 32 students attended the workshops at School B and 31 of them volunteered to participate in the research study by completing the workshop entry and exit surveys. The breakdown of these participants is shown in Table 24. Of the initial 31 students, 12 completed the end of semester survey, 4 of whom had attended a hands-on workshop and 8 of whom had attended a tour workshop.

Table 24: Workshop Participants, School B, Fall 2022

	Entry/Exit Surveys			End of Semester Survey		
	Hands On	Tour	Total	Hands On	Tour	Total
Black Engineers	3	0	3	1	0	1
Hispanic Engineers	4	10	14	1	3	4
First Generation	1	2	3	1	1	2
Women Engineers	5	6	11	1	4	5
Total	13	18	31	4	8	12

In Spring 2023, 14 students attended the workshops at School B and 13 of them volunteered to participate in the study by completing the workshop entry and exit surveys. The breakdown of these participants is shown in Table 25. Eight of the initial 13 filled out the end of semester survey, 5 of whom had attended a hands-on workshop and 3 of whom had attended a tour workshop. Combining the Fall 2022 and Spring 2023 participants left a sample of 9 hands-on participants and 11 tour participants for School B.

Table 25: Workshop Participants, School B, Spring 2023

	Entry/Exit Surveys			End of Semester Survey		
	Hands On	Tour	Total	Hands On	Tour	Total
Black Engineers	1	4	5	0	2	2
Hispanic Engineers	5	0	5	5	0	5
Latin Americans	0	3	3	0	1	1
Total	6	7	13	5	3	8

Finally, at School A, 12 students attended the workshops, and 9 of them participated in the study. These participants are shown in Table 26. Two students filled out the end of semester survey, 1 from the hands-on workshop, and 1 from the tour workshop. Because workshops were not held at School A in Fall 2022, this comprises the entire sample for School A.

Table 26: Workshop Participants, School A, Spring 2023

	Entry/Exit Surveys			End of Semester Survey		
	Hands On	Tour	Total	Hands On	Tour	Total
Hispanic Engineers	6	1	7	1	1	2
Women Mech. Engineers	0	1	1	0	0	0
Mechanical Engineers	0	1	1	0	0	0
Total	6	3	9	1	1	2

6.3.3 Preliminary Belonging Results

Table 27 and Figure 25 shows a comparison of belonging scores between the workshop entry and end of semester surveys for School B participants. Only the students who completed both are included in this analysis. Table 28 and Figure 26 show a comparison of end of semester belonging values between the hands-on workshop and tour workshop groups at School B. Because only 2 students completed both surveys at School A, no results are shown. Additionally, due to insufficient sample size, no conclusions can be drawn from data collected at either school, but these tables show the type of analysis that can be completed in the future.

Table 27: Entry vs End of Semester Survey Belonging Scores for Workshop Participants at School B

Survey Question	School B, n = 20, n = 20			
	Mean (Entry)	Mean (EndSem)	Z	p-value
1 I feel comfortable in the makerspace.	3.05	3.65	-1.508	0.132
2 I feel like I can really trust the student workers in the makerspace.	3.89	4.00	-0.372	0.71
3 I feel comfortable in engineering classrooms.	3.63	3.84	-0.468	0.64
4 I feel valued in the makerspace.	3.24	3.45	-0.761	0.447
5 I feel valued in engineering classrooms.	3.17	3.56	-1.195	0.232
6 I enjoy working on group projects in the makerspace.	3.31	3.60	-0.867	0.386
7 I'd like the chance to interact with the student workers in the makerspace more often.	3.68	3.79	-0.244	0.807
8 I have made friends through my work in the makerspace.	2.69	2.77	-0.266	0.791
9 I'd like a chance to interact with other students in the makerspace more often.	3.74	3.78	-0.131	0.896
10 I feel like I can really trust fellow students in the makerspace.	3.47	3.76	-0.969	0.332
11 I feel respected by my peers in the makerspace.	3.38	3.65	-0.737	0.461
12 I prefer to work with others in the makerspace.	2.93	2.24	-2.048	0.041*
13 I feel connected to fellow students in the makerspace.	3.36	3.06	-0.839	0.402

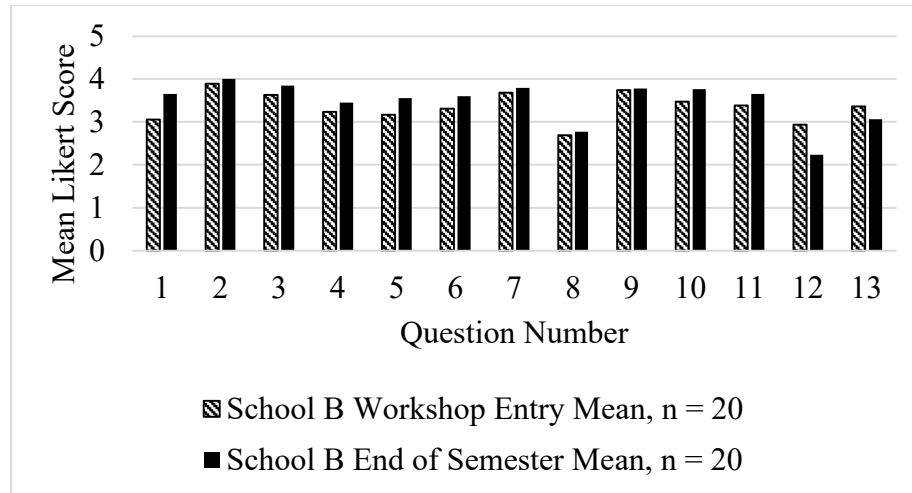


Figure 25: Entry vs End of Semester Belonging Questions Scores for Participants at School B

Table 28: Hands-On vs Tour Workshop End of Semester Belonging Scores for Participants at School B

Survey Question	School B, n = 9, n = 11			
	Mean Rank (HO)	Mean Rank (Tour)	Z	p-value
1 I feel comfortable in the makerspace.	3.44	3.82	-0.492	0.623
2 I feel like I can really trust the student workers in the makerspace.	3.78	4.18	-0.661	0.509
3 I feel comfortable in engineering classrooms.	3.63	4.00	-0.185	0.853
4 I feel valued in the makerspace.	3.22	3.64	-1.222	0.222
5 I feel valued in engineering classrooms.	3.14	3.82	-1.474	0.14
6 I enjoy working on group projects in the makerspace.	3.25	4.00	-1.988	0.047
7 I'd like the chance to interact with the student workers in the makerspace more often.	3.56	4.00	-1.031	0.302
8 I have made friends through my work in the makerspace.	2.75	2.80	-0.15	0.88
9 I'd like a chance to interact with other students in the makerspace more often.	3.44	4.11	-1.77	0.077
10 I feel like I can really trust fellow students in the makerspace.	3.56	4.00	-1.195	0.232
11 I feel respected by my peers in the makerspace.	3.22	4.13	-1.762	0.078
12 I prefer to work with others in the makerspace.	2.11	2.38	-0.709	0.478
13 I feel connected to fellow students in the makerspace.	2.89	3.25	-0.793	0.427

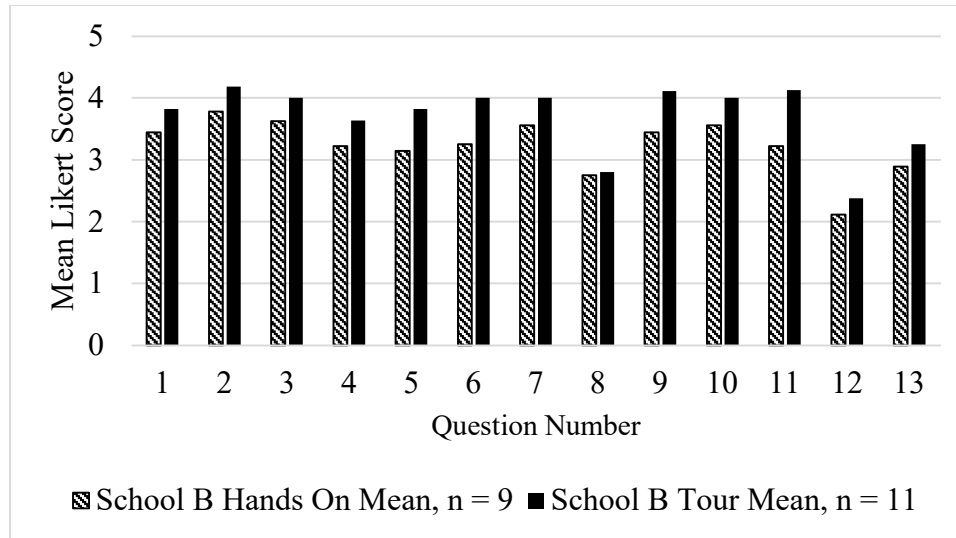


Figure 26: Hands On vs Tour End of Semester Belonging Scores for Participants at School B

6.3.4 Preliminary Tool Usage Results

In the workshop entry survey, students listed all the tools that they had *ever* used, inside or outside of academic makerspaces. In the end of semester survey, they listed the tools that they used *that semester*. This allowed for the researchers to identify any new tools that students used between the workshop and the end of the semester.

Table 29 shows the new tools used by students at School B in Fall 2022, Table 30 shows the new tools used by students at School B in Spring 2023, and Table 31 shows the new tools used by students at School A in Spring 2023. While references to the 3D printer or laser cutter by students in the hands-on group may refer to students learning to use those tools in the workshop, all other tools indicate new tools used. It is not guaranteed that these tools were used in the makerspace, though it is highly likely.

Table 29: New Tools Used by Students Who Attended Workshops at School B in Fall 2022

Workshop Participant	Workshop Type	New Tools Used
Student 2	Hands On	Pliers, Ultimaker 3D Printer*, Laser Cutter*
Student 5	Tour	None
Student 6	Hands On	3D Printer (Type Not Specified)*, Laser Cutter*
Student 8	Hands On	Ultimaker 3D Printer*, Laser Cutter*
Student 11	Tour	None
Student 15	Tour	None
Student 19	Tour	Bandsaw, Metal CNC, Belt Sander, Table Saw
Student 22	Tour	Vinyl/Paper Cutter
Student 24	Tour	None
Student 25	Tour	Electronics Tool (Didn't Know Name)
Student 26	Tour	None
Student 30	Hands On	Ultimaker 3D Printer*, Laser Cutter*

*May be referring to tool used during workshop

Table 30: New Tools Used by Students Who Attended Workshops at School B in Spring 2023

Workshop Participant	Workshop Type	New Tools Used
Student 2	Tour	Ultimaker 3D Printer, Sewing Machine
Student 5	Tour	Ultimaker 3D Printer, Met with a Group
Student 6	Tour	Embroidery Machine
Student 8	Hands On	Hand Tools (not specified)
Student 9	Hands On	Ultimaker 3D Printer*, CNC Wood Router
Student 10	Hands On	Polishing Wheel, Button Maker
Student 11	Hands On	Ultimaker 3D Printer*
Student 12	Hands On	None

*May be referring to tool used during the workshop

Table 31: New Tools Used by Students Who Attended Workshops at School A in Spring 2023

Workshop Participant	Workshop Type	New Tools Used
Student 3	Tour	None
Student 6	Hands On	3D Printer (unspecified)*

*May be referring to tool used during the workshop

While not much can be concluded from these results at this time, the substantial number of new tools that students used is encouraging and suggests that future workshops may be beneficial in recruiting more students to use the space. However, additional effort is likely needed to increase students' sense of belonging.

CHAPTER 7. CONCLUSIONS

An online survey consisting of questions about makerspace involvement, tool usage, and demographics was issued to makerspace users at two university makerspaces during Fall 2020, Spring 2021, Spring 2022, Fall 2022, and Spring 2023. The survey data were analyzed for metrics of frequency, tools used, and motivations for using the space. Additionally, qualitative questions asked students to elaborate on if and why they used the space less than other semesters.

Combined semester analysis revealed large disparities between tool usage at School A and School B with School B having generally higher usage and more diversity in usage types. At School A, all groups of students appear to utilize the makerspace's resources at similar rates, but makerspace usage is required for many classes and not permitted for personal projects. This is mostly likely part of the cause of the lower usage. At School B, students can use the makerspace resources for any project types, likely fueling their heavy usage, but large differences are still seen between men and women students. At both schools, tools introduced in class are used heavily throughout the remainder of the students' time in college.

Analysis of Spring semester data during and after COVID-19 showed that the makerspace health and student tool usage were much lower in Spring 2021, during the height of the COVID restrictions, than they were in Spring 2022 and Spring 2023 when the restrictions were removed. The decline was clearly seen across a variety of metrics including visit frequency, duration of usage, and tool usage. Interestingly, some tools such

as the 3D printer seemed less effected than others. Additionally, while both schools were affected, School B fared better due to a more open, less restricted environment.

While COVID was clearly a large disruption, it was found that similar tool usage analysis techniques can be used to identify and address other underlying issues. If the same processes are used routinely, makerspaces may be able to catch problems that arise such as harmful restrictions, problematic staff members, and other barriers to entry before they fully develop. Additionally, they give makerspace staff insight into the most popular and most valuable tools which can also be used to support curriculum and boost involvement.

Belonging questions asked in Fall 2022 and Spring 2023 surveys showed that students at both universities reported a high sense of belonging, but factors such as gender and study habits did produce statistically significant differences. Women students at School A felt more connected and respected by their peers in the makerspace and more valued in engineering classes while men students at School B reported a higher sense of comfort in both makerspaces and engineering classrooms. Similarly, those who studied in the makerspace not only reported higher levels of comfort, but also higher degrees of friendship and trust for peers around them. Majors and classes that require use of the makerspace also play a role in sense of belonging, though not as large.

Finally, a pilot study comprised of a series of hands-on and tour-based workshops offered to groups of students who are underrepresented in makerspaces produced promising results for using workshops to encourage students to use makerspaces. New tool usage improved as a result, though belonging was not affected. However, more work needs to be done.

In conclusion, makerspaces are a valuable tool in the hands of university students and educators, but they are not utilized evenly or consistently by all students. Continuing analysis such as that described has the potential to inform administrators of problems at hand. Makerspaces should be incredibly clear in their restriction policies and membership guidelines and seek to study their users to understand how best to serve their populations.

7.1 Limitations

A key limitation of this work is the lack of pre-COVID data. While pilot data were collected in Fall 2019 [72] prior to the start of the pandemic, the survey questions used were not directly comparable. Makerspace staff have stated that makerspace usage seems “back to normal” following COVID restrictions, but this is based fully on qualitative observation and there is no concrete pre-COVID data to back it up.

Another limitation is that the study’s participant makeup changed from semester to semester and from school to school, making it challenging to fully compare. This occurred despite using similar recruitment procedures each semester.

7.2 Future Work

The two makerspaces studied provide a good baseline for the metrics used and an understanding of how usage changes based on makerspace purpose. However, a larger pool of makerspaces would allow for much more concrete conclusions to be made.

Additionally, more workshops should be hosted to groups who are underrepresented in makerspaces. The initial results from this looked promising, but a substantial amount of additional work is needed to validate the results.

APPENDIX A. END OF SEMESTER SURVEY

End of Semester Survey, School B, Spring 2023

Consent form is below. Please read and then scroll all the way to the bottom to join the study.

Do you consent to participate in this study?

- ☐ Yes
- ☐ No

Skip To: End of Survey If Do you consent to participate in this study? = No

Are you currently enrolled as a School B student?

- ☐ Yes
- ☐ No

Skip To: End of Survey If Are you currently enrolled as a School B student? = No

- ☐ First name _____
- ☐ Last name _____

-
- ☐ Email: _____
- ☐ School B Username: _____
-

Please indicate the academic year you started at School B:

- ☐ 2022-2023
 - ☐ 2021-2022
 - ☐ 2020-2021
 - ☐ 2019-2020
 - ☐ 2018-2019
 - ☐ 2017-2018
 - ☐ 2016-2017
 - ☐ 2015-2016
 - ☐ 2014-2015
 - ☐ 2013-2014
 - ☐ Before 2013
-

Did you transfer from another university?

- ☐ Yes
 - ☐ No
-

What is your class standing by credit hours?

- ☐ Senior
 - ☐ Junior
 - ☐ Sophomore
 - ☐ Freshman
-

For the next section of the survey, we are investigating your involvement in university makerspaces. A university makerspace is a location associated with your university, designed to give prototyping access to students. Makerspaces give students access to prototyping equipment such as 3D printers and CNC machines for personal and/or class projects.

Examples of university makerspaces at School B include the...*(specific names inserted)*

Select the statement that best describes your familiarity with university makerspaces:

- ☐ I have never heard of any university makerspaces.
 - ☐ I have heard of university makerspaces, but I have never used any of the equipment and/or resources.
 - ☐ I have used a university makerspace's equipment and/or resources.
-

Which university makerspace(s) have you used before? Select all that apply.

- ☐ Specific makerspace names entered...
-

Are you or have you ever been a student volunteer or employee of a university makerspace?

- ☐ No, I have never been a student volunteer or employee of a university makerspace.
 - ☐ No, but I am interested in becoming one.
 - ☐ Yes, **I was** a student volunteer or employee of a university makerspace in a previous semester.
 - ☐ Yes, **I am currently** a student volunteer or employee of a university makerspace.
-

Please indicate the number of semesters you have been a student volunteer or employee of a university makerspace (if you have never been a student volunteer or employee, put 0)

Have you ever used a university makerspace to work on any of the following types of projects? Select all that apply.

- ☐ Class projects
 - ☐ Personal projects
 - ☐ Research projects
 - ☐ Entrepreneurial projects
 - ☐ Club or organization projects (student competitions, SCC, SAE, etc.)
 - ☐ Other (please specify): _____
-

During **this semester** (Spring 2023), have you used a university makerspace to work on any of the following types of projects? Select all that apply.

- ☐ Class projects
 - ☐ Personal projects
 - ☐ Research projects
 - ☐ Entrepreneurial projects
 - ☐ Club or organization projects (student competitions, SCC, SAE, etc.)
 - ☐ Did not use this semester
 - ☐ Other (please specify): _____
-

What organization(s) have you worked on projects for using makerspace equipment? (Please list, separated by commas). _____

Which classes have you ever used a university makerspace's equipment and/or resources? Select all that apply.

- ☐ Engineering Graphics (*Class Names and Numbers inserted*)
 - ☐ Sophomore Design
 - ☐ ME Capstone Design
 - ☐ Other Capstone Design
 - ☐ Other: _____
 - ☐ Other: _____
 - ☐ Other: _____
-

During **this semester** (Spring 2023), for which classes did you use a university makerspace's equipment and/or resources? Select all that apply.

- ☐ Engineering Graphics
- ☐ ME Sophomore Design
- ☐ ME Capstone Design
- ☐ Other Capstone Design
- ☐ Other: _____
- ☐ Other: _____
- ☐ Other: _____

Have you ever participated in any of the following activities utilizing a university makerspace? Select all that apply.

- ☐ Designing something
 - ☐ Building something
 - ☐ Fixing something
 - ☐ Collaborating with other students in a project
 - ☐ Helping students with their projects
 - ☐ Teaching other students how to use some piece of equipment
 - ☐ Advising students on how to approach a design problem
 - ☐ Learning how to use a piece of equipment
 - ☐ Participating in a university makerspace related events (e.g. Ladies Night)
 - ☐ Attending training session
 - ☐ Other (please specify): _____
-

How much time have you spent **this semester** (Spring 2023), during a typical week, in university makerspace related activities?

- ☐ None
 - ☐ Less than 1 hour
 - ☐ 1-2 hours
 - ☐ 3-5 hours
 - ☐ 6-10 hours
 - ☐ 11-20 hours
 - ☐ Over 20 hours
-

In comparison to **previous semesters**, how would you rank the amount of time you have spent during a typical week **this semester** (Spring 2023) in a university makerspace?

- ☐ I spent less time than previous semesters.
 - ☐ I spent as much time as previous semesters.
 - ☐ I spent more time than previous semesters.
 - ☐ This is my first semester being involved.
-

Please estimate the frequency in which you have been involved in university makerspace related activities **this semester** (Spring 2023)?

- ☐ Did not participate in any activities this past semester
 - ☐ Daily
 - ☐ 2-3 times a week
 - ☐ Once a week
 - ☐ 2-3 times a month
 - ☐ Once a month
 - ☐ Less than once a month
 - ☐ Once a semester
-

In comparison to **previous semesters**, how would you rate your involvement in a university makerspace during **this semester** (Spring 2023)?

- ☐ I was less involved than previous semesters.
 - ☐ I was as involved as previous semesters.
 - ☐ I was more involved than previous semesters.
 - ☐ This is my first semester being involved.
-

Please estimate the number of different projects (personal, classroom, research, club or organizational related, entrepreneurship) that you have worked on using any of a university makerspace's equipment and collaboration areas during **this semester** (Spring 2023)? (Please enter the numeral, not spelled out number, e.g. enter "3" not "Three"): _____

In comparison to previous semesters, how would you rank the number of projects you have worked on during a typical week this semester in a university makerspace?

- ☐ I have worked on fewer projects.
 - ☐ I have worked on about the same number of projects.
 - ☐ I have worked on more projects.
 - ☐ This is my first semester being involved.
-

If you did not use the university makerspace as much this semester as previous semesters or at all, why? _____

The following Questions were only included in the Workshop Participants version of the survey:

Did you attend any School B workshops or tours this semester?

- ☐ Yes, I attended a workshop or tour this semester.
- ☐ No, I did not attend a workshop or tour this semester.

Display This Question:

If Did you attend any School B workshops or tours this semester? = Yes, I attended a workshop or tour this semester.

Did you attend the workshop or tour with a particular student organization?

- ☐ Yes
- ☐ No

Display This Question:

If Did you attend the workshop or tour with a particular student organization? = Yes

Which workshop event did you attend?

- ☐ *Specific events and group names listed...*

Display This Question:

If Which workshop event did you attend? = One of the listed workshops

Did you receive your 3D printed part from the workshop?

- ☐ Yes
- ☐ No

This concludes the questions only in the Workshop Participants version of the survey

Please indicate which tools and activities you used/did this past semester (Spring 2023):
Select all that apply.

- ☐ 3D Printers or Scanners
 - ☐ Metal Room (CNC, waterjet, drill press, etc.)
 - ☐ Craft Tools (Vinyl/paper cutter, sewing machine, foam cutter, etc.)
 - ☐ Electronics Area (oscilloscope, power supplies, soldering, etc.)
 - ☐ Wood Tools
 - ☐ Handheld Tools (drills, screwdrivers, etc.)
 - ☐ Laser Cutter
 - ☐ Cad Station / Work Bench / White Boards
 - ☐ Studied / Just hung out / Met with a group
 - ☐ Got help or gave help
 - ☐ Working as Prototyping Instructor on Duty
 - ☐ Paint Booth
 - ☐ Welding
 - ☐ Bike Tools
 - ☐ Other equipment or activities not listed here (please specify): _____
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Handheld Tools (drills, screwdrivers, etc.)

Select the following Hand Tools you used this last semester (Spring 2023):

- ☐ All Hand Tools
 - ☐ Hammers
 - ☐ Pliers
 - ☐ Vice Grips
 - ☐ Clamps (C-clamp or other)
 - ☐ Screw Drivers
 - ☐ Hand Drills
 - ☐ Angle Grinder
 - ☐ Chisels
 - ☐ Measuring Tape
 - ☐ Table Vice
 - ☐ Glue Gun
 - ☐ Wire Cutters
 - ☐ Hand Saw
 - ☐ Dremel
 - ☐ Tap & Dye Set
 - ☐ Scissors
 - ☐ Tin Snips
 - ☐ X-ACTO Knife
 - ☐ Other (please enter name)
 - ☐ Other
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = 3D Printers or Scanners

Select the following types of 3D Printers or Scanners you used this last semester (Spring 2023):

- ☐ Ultimaker 3D Printers
 - ☐ Formlabs Resin 3D Printers
 - ☐ SLS Formiga
 - ☐ 3D Scanner - FARO Arm
 - ☐ Don't know
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Metal Room (CNC, waterjet, drill press, etc.)

Select the following Metal Room Tools you used this last semester (Spring 2023):

- ☐ Band Saw (Metal)
 - ☐ CNC Metal Mills
 - ☐ Manual Mill
 - ☐ Manual Lathe
 - ☐ Drill Press (Metal)
 - ☐ Belt Sander
 - ☐ Polishing Wheel
 - ☐ Waterjet
 - ☐ Sheet Metal Break
 - ☐ Cold Cut Saw
 - ☐ Metal Shears
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Wood Tools

Select the following Wood Room Tools you used this last semester (Spring 2023):

- ☐ Band Saw (Wood)
- ☐ Belt Sander
- ☐ Circular Saw
- ☐ Miter (Chop) Saw
- ☐ Jigsaw
- ☐ Drill Press (Wood)
- ☐ CNC Wood Router
- ☐ Router
- ☐ Planer
- ☐ Table Saw
- ☐ Jointer
- ☐ Wood Lathe
- ☐ Other
- ☐ Other
- ☐ Other

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Craft Tools (Vinyl/paper cutter, sewing machine, foam cutter, etc.)

Select the following Craft Tools you used this last semester (Spring 2023):

- ☐ Embroidery Machine (CNC Sewing Machine)
- ☐ Hot Wire Foam Cutter
- ☐ Sewing Machine
- ☐ Vinyl/Paper Cutter
- ☐ Button Maker
- ☐ Other

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Electronics Area (oscilloscope, power supplies, soldering, etc.)

Select the following Electronics Tools you used this last semester (Spring 2023):

- ☐ Circuit Board Plotter
 - ☐ Multimeter
 - ☐ Power Supply
 - ☐ Soldering Station
 - ☐ Oscilloscope
 - ☐ Logic Analyzer
 - ☐ Function Generator
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = CAD Station / Work Bench / White Boards

Select the following areas you used this last semester (Spring 2023):

- ☐ CAD Station
 - ☐ Workbenches/Tables
 - ☐ White Boards
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Studied / Just hung out / Met with a group

Select the following activities you participated in this last semester (Spring 2023):

- ☐ Studied
 - ☐ Hung Out
 - ☐ Met with a Group
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you used/did this past semester (Spring 2023): Select... = Got help or gave help

Select the following activities you participated in this last semester (Spring 2023):

- ☐ Got help from another student (not a student volunteer)
- ☐ Got help from a student volunteer
- ☐ I helped someone else
- ☐ Other

Think about when you first learned to use various tools in the makerspace. Can you list 5-10 tools in the approximate order of which you learned to use them?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

Think about the tools you learned this last semester (Spring 2023) in the makerspace. Please list as many as you can below.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

Please indicate which tools you had already learned before using the makerspace by dragging and dropping them into the box.

Tools already Learned (Box automatically expands as you add items)

Hand Tools

Laser Cutter

Ultimaker 3D Printer

Formlabs Resin 3D Printer

SLS Formiga

Stratasys 3D Printer

Faro Arm

3D Printer (not sure which one)

Band Saw (Metal)

CNC Metal Mill

Manual Mill

Manual Lathe

Drill press (Metal)

Belt Sander (Metal)
Polishing Wheel
Waterjet
Sheet Metal Break
Cold Cut Saw
Metal Shears
Bandsaw (Wood)
Belt sander (Wood)
Circular Saw
Miter (Chop) Saw
Jigsaw
Drill Press (Wood)
CNC Wood Router
Router
Planer
Table Saw
Jointer
Wood Lathe
Embroidery Machine
Foam Cutter
Sewing Machine
Vinyl/Paper Cutter
Button Maker
Circuit Board Prototyping
Multimeter
Power Supply
Soldering Station
Oscilloscope
Logic Analyzer

Function Generator

Other equipment not listed here (please specify):

Please indicate the approximate order you learned to use the following tools by dragging and dropping them. If you do not know how to use a tool, put it in the "Don't know how to use" box.

Order Learned (Box automatically expands as you add items)	Don't Know How to use
Hand Tools	
Laser Cutter	
Ultimaker 3D Printer	
Formlabs Resin 3D Printer	
SLS Formiga	
Stratasys 3D Printer	
Faro Arm	
3D Printer (not sure which one)	
Band Saw (Metal)	
CNC Metal Mill	
Manual Mill	
Manual Lathe	
Drill press (Metal)	
Belt Sander (Metal)	
Polishing Wheel	
Waterjet	
Sheet Metal Break	
Cold Cut Saw	
Metal Shears	
Bandsaw (Wood)	
Belt sander (Wood)	
Circular Saw	

Miter (Chop) Saw

Jigsaw

Drill Press (Wood)

CNC Wood Router

Router

Planer

Table Saw

Jointer

Wood Lathe

Embroidery Machine

Foam Cutter

Sewing Machine

Vinyl/Paper Cutter

Button Maker

Circuit Board Prototyping

Multimeter

Power Supply

Soldering Station

Oscilloscope

Logic Analyzer

Function Generator

Other equipment not listed here (please specify):

Do you have access to any of these types of tools at the place you live while in school?
(Your home, dorm, apartment, etc.)

- ☐ Yes, I have access to the following:
- ☐ No
-

Do you have access to a 3D printer at the place you live while in school? (Your home, dorm, apartment, etc.)

- ☐ Yes
 - ☐ No
-

What is your current major? Select one.

- ☐ Aerospace Engineering
 - ☐ Biomedical Engineering
 - ☐ Chemical Engineering
 - ☐ Computer Engineering
 - ☐ Electrical Engineering
 - ☐ Industrial Engineering
 - ☐ Material Science Engineering
 - ☐ Mechanical Engineering
 - ☐ Nuclear Engineering
 - ☐ Other (Please Specify)
-

Have you ever had a full or part time job?

- ☐ Yes
 - ☐ No
-

Have you ever had an internship or co-op? Select all that apply.

- ☐ Yes, I have had an internship.
 - ☐ Yes, I have had a co-op.
 - ☐ No, I have never had an internship or a co-op.
-

What is your gender?

- ☐ Please specify: _____
- ☐ Prefer not to disclose

What is your race/ethnicity? Select all that apply.

- ☐ White/Caucasian
 - ☐ Black or African American
 - ☐ American Indian or Alaskan Native
 - ☐ Native Hawaiian or Other Pacific Islander
 - ☐ Middle Eastern
 - ☐ Asian
 - ☐ Prefer not to disclose
 - ☐ Other
-

Do you consider yourself to be of Hispanic, Latinx, or of Spanish origin?

- ☐ Yes, Hispanic, Latinx, or of Spanish origin
 - ☐ No, not Hispanic, Latinx, or of Spanish origin
 - ☐ Prefer not to disclose
-

What is the highest level of education completed by either one of your parents or guardians?

- ☐ Did not complete high school
 - ☐ High school/GED
 - ☐ Some college
 - ☐ Bachelor's degree
 - ☐ Master's degree
 - ☐ Advanced graduate work or Ph.D.
 - ☐ Not Sure
-

What organizations on campus are you a member/involved in? (i.e. students competitions, honor societies, etc.) (Please list, separated by a comma). _____

Please indicate the degree to which you agree or disagree with the following statements:

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	N/A (6)
I feel comfortable in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel like I can really trust the student workers in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel comfortable in engineering classrooms.	☐	☐	☐	☐	☐	☐
I feel valued in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel valued in engineering classrooms.	☐	☐	☐	☐	☐	☐
I enjoy working on group projects in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I'd like the chance to interact with the student workers in the <i>makerspace</i> more often.	☐	☐	☐	☐	☐	☐
I have made friends through my work in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I'd like a chance to interact with other students in the <i>makerspace</i> more often.	☐	☐	☐	☐	☐	☐
I feel like I can really trust fellow students in the <i>makerspace</i> . (10)	☐	☐	☐	☐	☐	☐
I don't feel respected by my peers in the <i>makerspace</i> . (11)	☐	☐	☐	☐	☐	☐

I prefer to work alone in the <i>makerspace</i> . (13)	☐	☐	☐	☐	☐	☐
I feel disconnected to fellow students in the <i>makerspace</i> . (14)	☐	☐	☐	☐	☐	☐

Please indicate your satisfaction with the Invention Studio:

	Very Dissatisfied (1)	Somewhat Dissatisfied (2)	Neutral (3)	Somewhat Satisfied (4)	Very Satisfied (5)
How satisfied are you with the <i>makerspace</i>	☐	☐	☐	☐	☐

Any Additional Comments: _____

Thank you for completing this survey!

APPENDIX B. WORKSHOP SURVEYS

Workshop Entry Survey, School B, Spring 2023

Consent form is below. Please read and then scroll all the way to the bottom to join the study.

Do you consent to participate in this study?

- ☐ Yes
- ☐ No

Skip To: End of Survey If Do you consent to participate in this study? = No

- ☐ First name
- ☐ Last name
-

- ☐ Email: _____
- ☐ School B Username: _____
-

Which organization are you attending this workshop with?

Which workshop time slot are you attending?

- ☐ *Time Slots Listed*
-

For the next section of the survey, we are investigating your involvement in university makerspaces. A university makerspace is a location associated with your university, designed to give prototyping access to students. Makerspaces give students access to prototyping equipment such as 3D printers and CNC machines for personal and/or class projects.

Examples of university makerspaces at School B include the...*(specific names inserted)* _____

Select the statement that best describes your familiarity with university makerspaces:

- ☐ I have never heard of any university makerspaces.
 - ☐ I have heard of university makerspaces, but I have never used any of the equipment and/or resources.
 - ☐ I have used a university makerspace's equipment and/or resources.
-

Which university makerspace(s) have you used before? Select all that apply.

- ☐ Specific makerspace names entered...
-

Are you or have you ever been a student volunteer or employee of a university makerspace?

- ☐ No, I have never been a student volunteer or employee of a university makerspace.
 - ☐ No, but I am interested in becoming one.
 - ☐ Yes, **I was** a student volunteer or employee of a university makerspace in a previous semester.
 - ☐ Yes, **I am currently** a student volunteer or employee of a university makerspace.
-

Please indicate the number of semesters you have been a student volunteer or employee of a university makerspace (if you have never been a student volunteer or employee, put 0)

Have you ever used a university makerspace to work on any of the following types of projects? Select all that apply.

- ☐ Class projects
 - ☐ Personal projects
 - ☐ Research projects
 - ☐ Entrepreneurial projects
 - ☐ Club or organization projects (student competitions, SCC, SAE, etc.)
 - ☐ Other (please specify): _____
-

What organization(s) have you worked on projects for using makerspace equipment?
(Please list, separated by commas). _____

Which classes have you ever used a university makerspace's equipment and/or resources?
Select all that apply.

- ☐ Engineering Graphics (*Class Names and Numbers inserted*)
- ☐ Sophomore Design
- ☐ ME Capstone Design
- ☐ Other Capstone Design
- ☐ Other:
- ☐ Other:
- ☐ Other:

Have you ever participated in any of the following activities utilizing a university makerspace? Select all that apply.

- ☐ Designing something
- ☐ Building something
- ☐ Fixing something
- ☐ Collaborating with other students in a project
- ☐ Helping students with their projects
- ☐ Teaching other students how to use some piece of equipment
- ☐ Advising students on how to approach a design problem
- ☐ Learning how to use a piece of equipment
- ☐ Participating in a university makerspace related events (e.g. Ladies Night)
- ☐ Attending training session
- ☐ Other (please specify):

During your last semester on campus (Spring 2022, Summer 2022, etc.), how much time did you spend, during a typical week, in university makerspace related activities?

- ☐ None
 - ☐ Less than 1 hour
 - ☐ 1-2 hours
 - ☐ 3-5 hours
 - ☐ 6-10 hours
 - ☐ 11-20 hours
 - ☐ Over 20 hours
-

Please estimate the frequency in which you have been involved in university makerspace related activities during your last semester on campus (Spring 2022, Summer 2022, etc.)?

- ☐ Did not participate in any activities this past semester
 - ☐ Daily
 - ☐ 2-3 times a week
 - ☐ Once a week
 - ☐ 2-3 times a month
 - ☐ Once a month
 - ☐ Less than once a month
 - ☐ Once a semester
-

Please estimate the number of different projects (personal, classroom, research, club or organizational related, entrepreneurship) that you have worked on using any of a university makerspace's equipment and collaboration areas during **this semester** (Spring 2023)? (Please enter the numeral, not spelled out number, e.g. enter "3" not "Three"): _____

Please indicate which tools and activities you have used:

- ☐ 3D Printers or Scanners
 - ☐ Metal Room (CNC, waterjet, drill press, etc.)
 - ☐ Craft Tools (Vinyl/paper cutter, sewing machine, foam cutter, etc.)
 - ☐ Electronics Area (oscilloscope, power supplies, soldering, etc.)
 - ☐ Wood Tools
 - ☐ Handheld Tools (drills, screwdrivers, etc.)
 - ☐ Laser Cutter
 - ☐ Cad Station / Work Bench / White Boards
 - ☐ Studied / Just hung out / Met with a group
 - ☐ Got help or gave help
 - ☐ Working as Prototyping Instructor on Duty
 - ☐ Paint Booth
 - ☐ Welding
 - ☐ Bike Tools
 - ☐ Other equipment or activities not listed here (please specify):
-

Display This Question:

If Please indicate which tools and activities you have used. Select...= Handheld Tools (drills, screwdrivers, etc.).

Select the following Hand Tools that you have used:

- ☐ All Hand Tools
 - ☐ Hammers
 - ☐ Pliers
 - ☐ Vice Grips
 - ☐ Clamps (C-clamp or other)
 - ☐ Screw Drivers
 - ☐ Hand Drills
 - ☐ Angle Grinder
 - ☐ Chisels
 - ☐ Measuring Tape
 - ☐ Table Vice
 - ☐ Glue Gun
 - ☐ Wire Cutters
 - ☐ Hand Saw
 - ☐ Dremel
 - ☐ Tap & Dye Set
 - ☐ Scissors
 - ☐ Tin Snips
 - ☐ X-ACTO Knife
 - ☐ Other (please enter name)
 - ☐ Other
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you have used: Select... = 3D Printers or Scanners

Select the following 3D Printers or Scanners that you have used:

- ☐ Ultimaker 3D Printers
 - ☐ Formlabs Resin 3D Printers
 - ☐ SLS Formiga
 - ☐ 3D Scanner - FARO Arm
 - ☐ Don't know
 - ☐ Other_____
-

Display This Question:

If Please indicate which tools and activities you have used: Select... = Metal Room (CNC, waterjet, drill press, etc.)

Select the following Metal Room Tools that you have used:

- ☐ Band Saw (Metal)
 - ☐ CNC Metal Mills
 - ☐ Manual Mill
 - ☐ Manual Lathe
 - ☐ Drill Press (Metal)
 - ☐ Belt Sander
 - ☐ Polishing Wheel
 - ☐ Waterjet
 - ☐ Sheet Metal Break
 - ☐ Cold Cut Saw
 - ☐ Metal Shears
 - ☐ Other_____
-

Display This Question:

If Please indicate which tools and activities you have used: Select... = Wood Tools

Select the following Wood Room Tools that you have used:

- ☐ Band Saw (Wood)
- ☐ Belt Sander
- ☐ Circular Saw
- ☐ Miter (Chop) Saw
- ☐ Jigsaw
- ☐ Drill Press (Wood)
- ☐ CNC Wood Router
- ☐ Router
- ☐ Planer
- ☐ Table Saw
- ☐ Jointer
- ☐ Wood Lathe
- ☐ Other
- ☐ Other
- ☐ Other

Display This Question:

If Please indicate which tools and activities you have used: Select... = Craft Tools (Vinyl/paper cutter, sewing machine, foam cutter, etc.)

Select the following Craft Tools that you have used:

- ☐ Embroidery Machine (CNC Sewing Machine)
 - ☐ Hot Wire Foam Cutter
 - ☐ Sewing Machine
 - ☐ Vinyl/Paper Cutter
 - ☐ Button Maker
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you have used: Select... = Electronics Area (oscilloscope, power supplies, soldering, etc.)

Select the following Electronics Tools that you have used:

- ☐ Circuit Board Plotter
 - ☐ Multimeter
 - ☐ Power Supply
 - ☐ Soldering Station
 - ☐ Oscilloscope
 - ☐ Logic Analyzer
 - ☐ Function Generator
 - ☐ Other
-

Display This Question:

If Please indicate which tools and activities you have used: Select... = CAD Station / Work Bench / White Boards

Select the following areas you have used:

- ☐ CAD Station
 - ☐ Workbenches/Tables
 - ☐ White Boards
 - ☐ Other
-

Display This Question:

Please indicate which tools and activities you have used: Select... = Studied / Just hung out / Met with a group

Select the following activities you have done:

- ☐ Studied
 - ☐ Hung Out
 - ☐ Met with a Group
 - ☐ Other
-

Display This Question:

Please indicate which tools and activities you have used: Select... = Got help or gave help

Select the following activities you have done:

- ☐ Got help from another student (not a student volunteer)
- ☐ Got help from a student volunteer
- ☐ I helped someone else
- ☐ Other

Please indicate the degree to which you agree or disagree with the following statements:

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	N/A (6)
I feel comfortable in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel like I can really trust the student workers in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel comfortable in engineering classrooms.	☐	☐	☐	☐	☐	☐
I feel valued in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I feel valued in engineering classrooms.	☐	☐	☐	☐	☐	☐
I enjoy working on group projects in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I'd like the chance to interact with the student workers in the <i>makerspace</i> more often.	☐	☐	☐	☐	☐	☐
I have made friends through my work in the <i>makerspace</i> .	☐	☐	☐	☐	☐	☐
I'd like a chance to interact with other students in the <i>makerspace</i> more often.	☐	☐	☐	☐	☐	☐
I feel like I can really trust fellow students in the <i>makerspace</i> . (10)	☐	☐	☐	☐	☐	☐
I don't feel respected by my peers in the <i>makerspace</i> . (11)	☐	☐	☐	☐	☐	☐
I prefer to work alone in the <i>makerspace</i> . (13)	☐	☐	☐	☐	☐	☐

I feel disconnected to
fellow students in the
makerspace. (14)

☐☐☐☐☐☐

Workshop Exit, School B, Spring 2023

☐ First name

☐ Last name

☐ Email:

☐ School B Username:

What is your current major? Select one.

- ☐ Aerospace Engineering
 - ☐ Biomedical Engineering
 - ☐ Chemical Engineering
 - ☐ Computer Engineering
 - ☐ Electrical Engineering
 - ☐ Industrial Engineering
 - ☐ Material Science Engineering
 - ☐ Mechanical Engineering
 - ☐ Nuclear Engineering
 - ☐ Other (Please Specify)
-

Have you ever had a full or part time job?

- ☐ Yes
 - ☐ No
-

Have you ever had an internship or co-op? Select all that apply.

- ☐ Yes, I have had an internship.
 - ☐ Yes, I have had a co-op.
 - ☐ No, I have never had an internship or a co-op.
-

What is your gender?

- ☐ Please specify: _____
 - ☐ Prefer not to disclose
-

What is your race/ethnicity? Select all that apply.

- ☐ White/Caucasian
 - ☐ Black or African American
 - ☐ American Indian or Alaskan Native
 - ☐ Native Hawaiian or Other Pacific Islander
 - ☐ Middle Eastern
 - ☐ Asian
 - ☐ Prefer not to disclose
 - ☐ Other
-

Do you consider yourself to be of Hispanic, Latinx, or of Spanish origin?

- ☐ Yes, Hispanic, Latinx, or of Spanish origin
 - ☐ No, not Hispanic, Latinx, or of Spanish origin
 - ☐ Prefer not to disclose
-

What is the highest level of education completed by either one of your parents or guardians?

- ☐ Did not complete high school
- ☐ High school/GED
- ☐ Some college
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ Advanced graduate work or Ph.D.
- ☐ Not Sure

Any Additional Comments: _____

Thank you for completing this survey!

REFERENCES

- [1] D. Dougherty, "The Maker Movement," *Innovations: Technology, Governance, Globalization*, vol. 7, no. 3, pp. 11-14, 2012.
- [2] K. Peppler, & Bender, S., "Maker Movement Spreads Innovation One Project at a Time," *The Phi Delta Kappan*, vol. 95, no. 3, pp. 22-27, November 2013.
- [3] E. C. Hilton, Talley, K. G., Smith, S. F., Nagel, R. L., & Linsey, J. S., "Report on Engineering Design Self-Efficacy and Demographics of Makerspace Participants Across Three Universities.," *Journal of Mechanical Design*, vol. 142, no. 10, May 8th 2020. [Online]. Available: <https://doi.org/10.1115/1.4046649>.
- [4] R. M. Carbonell, Andrews, M. E., Boklage, A., & Borrego, M. J., "Innovation, Design, and Self-Efficacy: The Impact of Makerspaces," presented at the 2019 ASEE Annual Conference & Exposition, , Tampa, FL, June 15th, 2019. [Online]. Available: <https://peer.asee.org/32965>.
- [5] E. Hilton, Tomko, M., Murphy, A., Nagal, R., & Linsey, J., "Impacts on Design Self-Efficacy for Students Choosing to Participate in a University Makerspace.," in *The Fifth International Conference on Design Creativity*, Bath, UK, 2018, pp. 369-378.
- [6] M. Galaleldin, Bouchard, F., Anis, H., & Lague, C., "The Impact of Makerspaces on Engineering Education," presented at the Proceedings of the 2016 Canadian Engineering Education Association (CEEAA) Conference, Halifax, Canada, January 28th, 2017.
- [7] J. Bouwma-Gearhart, Ha Choi, Y., Lenhart, C. A., Villanueva, I., Nadelson, L. S., & Soto, E., "Undergraduate Students Becoming Engineers: The Affordances of University-Based Makerspaces," *Sustainability*, vol. 13, no. 4, February 4th 2021.
- [8] L. Nadelson, Villanueva, I., Bouwma-Gearhart, J., Lanci, S., Youmans, K., Lenhart, C. A., & Van Winkle, A. K., "Knowledge in the Making: What Engineering Students are Learning in Makerspaces," presented at the 2019 ASEE Annual Conference & Exposition, Tampa, FL, June 15th, 2019. [Online]. Available: <https://peer.asee.org/33039>.
- [9] A. Longo, Yoder, B. & Geurra, R. C. C., "University Makerspaces: Characteristics and Impact on Student Success in Engineering and Engineering Technology Education.," presented at the 2017 ASEE Annual Conference & Exposition, Columbus, OH, June 24th - 28th, 2017.
- [10] M. N. Cooke, & Charnas, I. C., "The Value of Data, Metrics, and Impact for Higher Education Makerspaces," *International Journal of Academic Makerspaces and*

Making, vol. 1, no. 1, April 1st 2021. [Online]. Available: <https://doi.org/10.21428/70cb44c5.72b2375c>.

- [11] K. Harmer, & Kaip, J., "Data Collection in an Academic Library Maker Space; Methods to Define Success and Inform Decision Making.," presented at the 2019 International Symposium on Academic Makerspaces, New Haven, CT., October 16th-18th, 2019.
- [12] R. Imam, L. Ferron, and A. Jarriwala, "A Review of the Data Collection Methods Used at Higher Education Makerspaces," presented at the 3rd International Symposium on Academic Makerspaces, Palo Alto, CA, August 3rd - 5th, 2018.
- [13] J. Linsey, Forest, C., Nagel, R., Newstetter, W., Talley, K. G., & Smith, S., "Understanding the Impact in University Makerspaces. ," presented at the 2016 International Symposium on Academic Makerspaces, Cambridge, MA, November 13th - 16th, 2016.
- [14] M. Tomko, Nagel, R., Linsey, J., Aleman., "A Qualitative Approach to Studying the Interplay Between Expertise, Creativity, and Learning in University Makerspaces.," presented at the 2017 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference., Cleveland, OH, August 6th - 9th, 2017.
- [15] M. Culpepper and J. Hunt, "Don't GUESS, It's Easy to Get the Information That Lets You KNOW How to Create and Run Your Makerspace and Makersystem," presented at the 1st International Symposium on Academic Makerspaces, Cambridge, MA, November 13th-16th, 2016.
- [16] W. Ulrich, M. Almeida-Neto, and N. J. Gotelli, "A consumer's guide to nestedness analysis," *Oikos*, vol. 118, 2009, doi: 10.1111/j.1600-0706.2008.17053.x.
- [17] T. J. Matthews, H. E. W. Cottee-Jones, and R. J. Whittaker, "Quantifying and interpreting nestedness in habitat islands: a synthetic analysis of multiple datasets," *Diversity and Distributions*, vol. 21, no. 4, pp. 392-404, 2015, doi: 10.1111/ddi.12298.
- [18] R. Heleno, M. Devoto, and M. Pocock, "Connectance of species interaction networks and conservation value: Is it any good to be well connected?," *Ecological Indicators*, vol. 14, no. 1, pp. 7-10, 2012, doi: 10.1016/j.ecolind.2011.06.032.
- [19] J. Bascompte, P. Jordano, C. J. Melián, and J. M. Olesen, "The nested assembly of plant-animal mutualistic networks," *The Proceedings of the National Academy of Sciences (PNAS)*, vol. 100, no. 16, pp. 9383-9387, 2003, doi: 10.1073/pnas.1633576100.
- [20] S. Blair, H. Banks, G. Hairtson, J. Linsey, and A. Layton, "Modularity Analysis of Makerspaces to Determine Potential Hubs and Critical Tools in the Makerspace," *2022 ASEE Annual Conference & Exposition*, 2022.

- [21] S. E. Blair, G. Hairtson, H. D. Banks, J. S. Linsey, and A. Layton, "Makerspace Network Analysis for Identifying Student Demographic Usage," *IJAMM*, 2022.
- [22] S. E. Blair, J. S. Linsey, A. Layton, and H. D. Banks, "Bipartite Network Analysis Utilizing Survey Data to Determine Student and Tool Interactions in a Makerspace," *ASEE Virtual Annual Conferense*, 2021.
- [23] J. Lewis, "Barriers to Women's Involvement In Hackspaces and Makerspaces," September, 2015.
- [24] M. Tomko, Aleman, M. W., Newstetter, W., Nagel, R. L., & Linsey, J., "Participation Pathways for Women into University Makerspaces.," *Journal of Engineering Education*, vol. 110, no. 3, pp. 700-717, June 15th 2021. [Online]. Available: <https://doi.org/10.1002/jee.20402>.
- [25] D. Smit, & Fuchsberger, V., "Sprinkling Diversity: Hurdles on the Way to Inclusiveness in Makerspaces.," presented at the NordiCHI 2020 - 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society, Tallinn, Estonia, October 25th, 2020. [Online]. Available: <https://doi.org/10.1145/3419249.3420070>.
- [26] A. Smalley. "Higher Education Responses to Coronavirus (COVID-19)." <https://www.ncsl.org/education/higher-education-responses-to-coronavirus-covid-19> (accessed June 1st, 2023).
- [27] V. Bill and A.-L. Fayard, "Resilience and Innovation in Response to COVID-19: Learnings from Northeast Academic Makerspaces," presented at the 2021 ASEE Annual Conference and Exposition, Virtual 2021.
- [28] S. Lieber, J. Suriano, and D. Brateris, "Making It Happen: Findings from Processes Implemented to Continue Operating a University Makerspace During the COVID-19 Pandemic. ," presented at the ASEE, Virtual, 2021.
- [29] N. Lou and K. Peek, "By The Numbers: The Rise of The Makerspace," *Popular Science*. [Online]. Available: <https://www.popsoci.com/rise-makerspace-by-numbers/>
- [30] P. Blikstein, "Maker Movement in Education: History and Prospects.," in *Handbook of Technology Education*, 2018, pp. 419-437.
- [31] T. Barrett, M. Pizzico, B. Levy, and R. Nagel, "A Review of University Makerspaces," presented at the ASEE Annual Conference & Exposition, Seattle, WA, June 14-17, 2015.
- [32] E. R. Halverson, & Sheridan, K. M., "The Maker Movement in Education," *Harvard Educational Review*, vol. 84, no. 4, 2014.

- [33] V. Wilczynski, "Academic Maker Spaces and Engineering Design," presented at the 122nd ASEE Annual Conference & Exposition, Seattle, WA, June 14th-17th, 2015.
- [34] C. Forest, & Farzaneh, H. H., "Quantitative Survey and Analysis of Five Maker Spaces at Large, Research-Oriented Universities.," presented at the 2016 ASEE Annual Conference & Exposition, New Orleans, LA, June 26th - 29th, 2016.
- [35] M. Tomko, M. Alemán, R. Nagel, W. Newstetter, and J. Linsey, "A typology for learning: Examining how academic makerspaces support learning for students," *Journal of Mechanical Design*, pp. 1-19, 2023, doi: 10.1115/1.4062701.
- [36] T. Sawchuk, E. Hilton, R. Nagel, and J. Linsey, "Understanding Academic Makerspaces through a Longitudinal Study at Three Universities," presented at the American Society for Engineering Education Annual Conference, Tampa, FL, 2019.
- [37] R. Morocz *et al.*, "Relating Student Participation in University Maker Spaces to their Engineering Design Self-Efficacy," in *American Society for Engineering Education Annual Conference*, New Orleans, LA, 2016.
- [38] E. C. Hilton, Nagel, R., Linsey, J., "Makerspace Involvement and Academic Success in Mechanical Engineering.," in *2018 IEEE Frontiers in Education Conference (FIE)*, San Jose, CA, October 3rd - 6th 2018.
- [39] S. Farritor, "University-Based Makerspaces: A Source of Innovation," *Technology and Innovation*, vol. 19, pp. 389-395, 2017.
- [40] N. Taylor, Hurley, U., & Connolly, P., "Making Community: The Wider Role of Makerspaces in Public Life.," presented at the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, CA, May 7th, 2016. [Online]. Available: <https://doi.org/10.1145/2858036.2858073>.
- [41] M. Jennings, Coley, B. C., Boklage, A. R., & Kellam, N. N., "Listening to Makers: Exploring Engineering Students' Recommendations for Creating a Better Makerspace Experience.," presented at the 2019 ASEE Annual Conference & Exposition, Tampa, FL., June 15th, 2019. [Online]. Available: <https://strategy.asee.org/33067>.
- [42] J. Hunt, Goodner, R. E., & Jay, A., "Comparing Male and Female Student Responses on MIT Maker Survey: Understanding the Implications and Strategies for More Inclusive Spaces.," presented at the 2019 International Symposium on Academic Makerspaces, New Haven, CT, October 16th - 18th, 2019.
- [43] A. Noel, Murphy, L., & Jariwala, A. S., "Sustaining a Diverse and Inclusive Culture in a Student Run Makerspace.," presented at the 2016 International Symposium on Academic Makerspaces, Cambridge, MA, November 13th - 16th, 2016.

- [44] E. Bravo and J. Breneman, "What is an Equitable Academic Makerspace? ," presented at the 6th International Symposium on Academic Makerspaces, Atlanta, GA, November 6th-9th, 2022.
- [45] C. K. Lam, Cruz, S. N., Kellam, N. N., & Coley, B. C., "Making Space for the Women: Exploring Female Engineering Student Narratives of Engagement in Makerspaces.," presented at the 2019 ASEE Annual Conference & Exposition, Tampa, FL, June 15th, 2019. [Online]. Available: <https://peer.asee.org/33078>.
- [46] J. Whyte, & Misquith, C., "By Invitation Only: The Role of Personal Relationships in Creating an Inclusive Makerspace Environment.," presented at the 2017 International Symposium on Academic Makerspaces, Cleveland, OH, September 24th - 27th, 2017, 102.
- [47] S. Lanci, Nadelson, L., Villanueva, I., Bouwma-Gearhart, J., Youmans, K. L., & Lenz, A., "Developing a Measure of Engineering Students' Makerspace Learning, Perceptions, and Interactions.," presented at the 2018 ASEE Annual Conference & Exposition, Salt Lake City, UT, June 23rd, 2018. [Online]. Available: <https://peer.asee.org/30292>.
- [48] L. Nadelson, Villanueva, I., Bouwma-Gearhart, J., Soto, E., Lenhart, C. A., Youmans, K., & Choi, Y. H., "Student Perceptions of and Learning in Maker Spaces Embedded in Their Undergraduate Engineering Preparation Programs.," presented at the 2020 ASEE Virtual Annual Conference Content Access, Online, June 22nd, 2020. [Online]. Available: <https://peer.asee.org/35230>.
- [49] K. E. Aidala, Baker, N., Feldman, R., Klemperer, P. F., Mensing, S., & St. John, A., "Empowering the Liberal Arts Student: Tech for All.," presented at the 2017 International Symposium on Academic Makerspaces, Cleveland, OH, September 24th - 27th, 2017.
- [50] A. H. Maslow, "A Theory of Human Motivation," *Psychological Review*, vol. 50, no. 4, pp. 430-437, 1943.
- [51] K. Lewis *et al.*, "Fitting in to Move Forward: Belonging, Gender, and Persistence in the Physical Science, Technology, Engineering, and mathematics (pSTEM)," *Psychology of Women Quarterly*, vol. 41, no. 4, pp. 420-436, 2017.
- [52] H. Korpershoek, E. T. Canrinus, M. Fokkens-Bruinsma, and H. de Boer, "The relationships between school belonging and students' motivational, social-emotional, behavioural, and academic outcomes in secondary education: a meta-analytic review," *Research Papers in Education*, vol. 35, no. 6, pp. 641-680, 2020/11/01 2020, doi: 10.1080/02671522.2019.1615116.
- [53] L. Hausmann, J. Schofield, and R. Woods, "Sense of Belonging as a Predictor of Intentions to Persist Among African American and White First-Year College Students," *Research in Higher Education*, vol. 48, pp. 803-839, 2007.

- [54] S.-Y. Han, J. Yoo, H. Zo, and A. P. Ciganek, "Understanding makerspace continuance: A self-determination perspective," *Telematics and Informatics*, vol. 34, no. 4, pp. 184-195, 2017/07/01/ 2017, doi: <https://doi.org/10.1016/j.tele.2017.02.003>.
- [55] L. S. Jensen, Ozkil, A. G., & Mougaard, K., "Makerspaces in Engineering Education: A Case Study," presented at the ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Charlotte, NC, August 21st - 24th, 2016.
- [56] W. Roldan, Hui, J., & Gerber, E., "University Makerspaces: Opportunities to Support Equitable Participation for Women in Engineering," *International Journal of Engineering Education*, vol. 34, no. 2, pp. 751-768, 2018.
- [57] N. Holbert, "Bots for Tots: Building Inclusive Makerspaces by Leveraging "Ways of Knowing"." presented at the IDC 2016 - The 15th International Conference on Interaction Design and Children, Manchester, UK, June 21st, 2016.
- [58] A. M. Lederer, M. T. Hoban, S. K. Lipson, S. Zhou, and D. Eisenberg, "More Than Inconvenienced: The Unique Needs of U.S. College Students During the COVID-19 Pandemic," *Health Education & Behavior*, vol. 48, no. 1, pp. 14-19, 2021, doi: 10.1177/1090198120969372.
- [59] S. Bartolic *et al.*, "Student vulnerabilities and confidence in learning in the context of the COVID-19 pandemic," *Studies in Higher Education*, vol. 47, no. 12, pp. 2460-2472, 2022/12/02 2022, doi: 10.1080/03075079.2022.2081679.
- [60] L. Y. Saltzman, T. C. Hansel, and P. S. Bordnick, "Loneliness, Isolation, and Social Support Factors in Post-COVID-19 mental health.," *Psychological Trauma: Theory, Research, Practice, and Policy*, vol. 12, no. 1, pp. S55-S57, 2020.
- [61] A. Boklage, R. Carbonell, and M. Andrews, "Making change: instructional pivots of academic makerspace projects during the COVID-19 pandemic," *European Journal of Engineering Education*, vol. 47, no. 6, pp. 1009-1035, 2022/11/02 2022, doi: 10.1080/03043797.2022.2098693.
- [62] M. A. Melo, Laura%AHirsh, Kimberly%Anull Ed.%BJournal Name: Proceedings of the Association for Library and I. S. E. A. Conference, "Examining the impacts of the covid-19 pandemic on library makerspaces and LIS makerspace curricula," *Journal Name: Proceedings of the Association for Library and Information Science Education Annual Conference*, p. Medium: X, 2021.
- [63] M. Kinnula, I. Sánchez Milara, B. Norouzi, S. Sharma, and N. Iivari, "The show must go on! Strategies for making and makerspaces during pandemic," *International Journal of Child-Computer Interaction*, vol. 29, p. 100303, 2021/09/01/ 2021, doi: <https://doi.org/10.1016/j.ijcci.2021.100303>.

- [64] J. Lewis, N. Hawkins, T. Tretter, F. B. Chan, and B. Robinson, "Converting a First-Year Engineering, Makerspace Course into COVID-Necessitated Fully-Online Synchronous Delivery and Related Student Perceptions," presented at the ASEE, Minneapolis, MN, 2022.
- [65] H. D. Budinoff, J. Bushra, and M. Shafae, "Community-driven PPE production using additive manufacturing during the COVID-19 pandemic: Survey and lessons learned," *Journal of Manufacturing Systems*, vol. 60, pp. 799-810, 2021/07/01/2021, doi: <https://doi.org/10.1016/j.jmsy.2021.07.010>.
- [66] J. McGuffin-Cawley and V. Wilczynski, "University Makerspaces and Manufacturing Collaboration: Lessons from the Pandemic," *The Bridge*, vol. 51, no. 1, 3/31/23 2021.
- [67] R. Imam, P. Patel, L. Ferron, and A. Jarriwala, "Development and Impact of a Data Collection System for Academic Makerspaces," presented at the 2nd International Symposium on Academic Makerspaces, Cleveland, OH, September 24th-27th, 2017.
- [68] E. Schoop, Huang, F., Khuu, N., & Hartmann, B., "MakerLens: What Sign-In, Reservation and Training Data Can (and Cannot) Tell You About Your Makerspace.," presented at the 2018 International Symposium on Academic Makerspaces, Palo Alto, CA, August 3rd - 5th, 2018.
- [69] N. M. Bradburn, Rips, L. J., & Shevell, S. K., "Answering Autobiographical Questions: The Impact of Memory and Inference on Surveys," *Science*, vol. 236, no. 4798, pp. 157-161, May 1987.
- [70] T. Araujo, Wonneberger, A., Neijens, P., & De Vreese, C., "How Much Time Do You Spend Online? Understanding and Improving the Accuracy of Self-Reported Measures of Internet Use.," *Communication Methods and Measures*, vol. 11, no. 3, pp. 173-190, April 27th 2017. [Online]. Available: <https://doi.org/10.1080/19312458.2017.1317337>.
- [71] T. Kato, & Miura, T., "The Impact of Questionnaire Length on the Accuracy Rate of Online Surveys," *Journal of Marketing Analytics*, vol. 9, pp. 83-98, February 17th 2021. [Online]. Available: <https://doi.org/10.1057/s41270-021-00105-y>.
- [72] H. Banks, "A Comparison of Tool Use Rates in Two Makerspaces During COVID," MS Thesis, GT, 2023.