A COMPARISON OF TOOL USE RATES IN TWO MAKERSPACES DURING COVID

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Makerspaces have rapidly established themselves in engineering education as a valuable means to enhance design confidence and learning outcomes. As these spaces continue to grow in popularity, it is pertinent to understand exactly how makerspaces are being used. This knowledge ensures that engineering learning outcomes are being enhanced effectively and equitably.

This work presents the results of a survey-based characterization of two makerspaces at two different institutions. The goals of this work are to better understand how makerspaces are being used and of the factors that influence how students interface with the space. Findings show that between institutions there are differences in the extent students engage with the space, as well as between what tools and activities students engage in while using these facilities. Interestingly, for students who are already using the space, we did not find differences for men versus women or Hispanic/Latinx compared to non-Hispanic/Latinx in the extent to which students use the space, or the rates they use tools at. The current data only measures students who are already using the space. The survey also received higher response rates for underrepresented minority (URM) and women students. Considering prior literature reporting that women experience substantial barriers in STEM and makerspaces. In future work it will be necessary to collect data regarding students' satisfaction with the space to further investigate URM students' experiences in these spaces.

Using makerspaces to support engineering coursework can have mixed effects on students' tool use. There is a general trend that students who use the space for class use a

greater variety of tools. This trend, however, is not consistent across tools or institutions, potentially because the tool training requirements, types of projects, and curriculum of making related courses varies substantially from course to course, as well as between institutions.

The Covid-19 pandemic saw many restrictions placed on makerspaces that reduced the number of students that used the space as well as the number of tools those students used. Said restrictions however provide an interesting opportunity to study a less effective makerspace, the resilience of makerspaces, and to potentially identify which tools in the makerspace students are easily deterred from use and which they are not. A notable activity that students continued doing in makerspaces during Covid were social activities, despite social distancing policies. Furthermore, students that used the space for social activities interacted with the rest of the makerspace to a much greater extent than their peers. Whether socialization is just correlated, or a cause of increased makerspace engagement remains uncertain.

There are undoubtedly factors other than those identified in this work that are contributing to how these two makerspaces are being used by students. This work however provides a detailed empirical characterization of how these makerspaces are being used that has highlighted several factors of interest worthy of further investigation. This represents an important step in developing a broader understanding of how makerspaces are used, and how they can be designed and managed for optimal making and learning outcomes.

INTRODUCTION

Active learning and other novel educational methods have grown drastically in popularity over the last several decades, with makerspaces being one advent of this broader movement that have stood out [1-4]. Makerspaces facilitate learning by providing tooling, dedicated making environments, and mentorship that allows students to engage in creative activities they otherwise would not have the opportunity for. Makerspaces are used in a diverse set of applications, ranging from university prototyping facilities to extensions of K-12 libraries geared for spurring interest in STEM [5-7]. Makerspaces are certainly not the only successful implementation of active learning used in higher STEM education, with lab courses, capstone projects, introductory design courses becoming integral to most all engineering programs [1, 2, 8, 9]. Makerspaces are complementary to these previously established active learning processes. Makerspaces, for instance, enable capstone projects and labs with tooling that allows for students to pursue more diverse and advanced projects. Makerspaces provide students with more advanced tooling and training allowing for engineering curriculum that better embodies industry engineering work, familiarizing students with contemporary manufacturing methods and encouraging them to develop their CAD and prototyping skills.

In addition makerspaces and making in general have been correlated with increased design confidence as well as improving design and communication skills [10-13]. Providing a dedicated space for students to design, fail, and design again affords students the opportunity not only to hone their explicit design skills taught in class but lends itself to better academic success [14] and improved expectations of design success [11].

While many use cases of makerspaces such as class or hobby-based use have already been identified, there is still substantial room for improvement with respect to our understanding of why and how makerspaces are specifically used [15, 16]. Furthermore, makerspace design, management, academic performance and demographic factors are thought to influence how students interact with a makerspace [14, 15, 17-20]. How these factors influence the specific tools a student decides to use, the activities they engage in, and connections that they make within a makerspace, is not well characterized. Considering the observed correlational relationship between makerspace involvement and academic success [14], it is pertinent to study the extent to which students are making use of the space. Especially considering that there is a plethora of literature identifying barriers to under-represented minorities (URM) and women that adversely impact makerspace involvement [17, 21, 22]. By developing our understanding of how these spaces are being used, by whom, and which tools they are using, engineering educators can be better equipped to design spaces that yield optimal learning opportunities, as well as ensure that learning outcomes are equitable with respect to race, gender and ethnicity.

While better understanding the barriers that may inhibit makerspace use and other making outcomes are a major point of interest for this work, the fact that this work was in part conducted during the Covid-19 pandemic presents a unique opportunity to better understand makerspace use likely creating significant barriers to makerspace use and less functional makerspaces. Covid-19 is a novel coronavirus that reached pandemic status in March of 2020 [23]. This pandemic saw widespread supply chain shocks, as well as drastic, unprecedented actions taken by industry, academia, and all other institutions. In academia, these restrictions initially consisted of a shift to entirely virtual instruction with extremely limited in-person instruction opportunities. By the Fall of 2021, most courses at universities returned to offering in-person options while still maintaining virtual options at levels higher than they were before the pandemic. The makerspace restrictions that accompanied the pandemic reduced the extent to which students used makerspaces. Accordingly, in observing how students use the makerspace during periods when they are subject to Covid restrictions may highlight which tools and motivations are the most resilient to this type of adversity and the effects of barriers to makerspace use. Conversely, it may show which making activities are the least important to students, and most easily deterred.

Understanding how this resiliency varies between different tools and activities within the makerspaces may complement our understanding of why students use makerspace and how they prioritize different making activities. Furthermore, it may reveal that there are certain tools that students are easily swayed from using, in which case it may point educators towards taking action to ensure these tools are easily accessible and approachable. The research questions for this work are:

1. *How are students using makerspaces? And which demographic/academic factors have the most impactful implications for makerspace use?*
2. *How does makerspace use change when students are faced with considerable barriers (i.e. Covid-19 and corresponding restrictions)?*

The goal of this work is to lay additional groundwork for a more informed approach to makerspace design. While students have already derived superior learning experiences thanks to makerspaces, there are many frictions that can be avoided and opportunities that can be capitalized on to further improve these spaces. By studying how these two makerspaces are specifically used, what makes them tick, and how Covid has influenced them may serve as an important initial step towards ultimately developing a comprehensive set of makerspace design heuristics.

BACKGROUND

1.1 Benefits of Makerspaces

Makerspaces are thought to benefit STEM education by facilitating hands-on design problems that test and bolster students' classroom-based conceptual understanding [2, 4, 24]. Students often overestimate their own knowledge and abilities [25, 26], but by challenging students with tangible open-ended design problems it affords them the opportunity to make mistakes in a forgiving environment and develop a more complete understanding than they would have from a lecture-based education. The act of making, iterating and learning from past mistakes shows students that engineering problems are more manageable than they seem and well within their grasp. As said by Adam Savage, the host of 'Mythbusters' and long-time advocate of the maker movement: "when you make something the world becomes a little more parsable, it becomes a little more understandable … when you're making the thing, going through the process, the problem-solving, the shaping your future with your hands, it's an inherently good and positive conversation [27]." Students often speak of a similar effect after using makerspaces, noting that the failures they experience in makerspaces are an important dimension of the learning environment that makerspaces foster [28].

As engineering design becomes more technical and complex, it may become an equally more challenging and intimidating task for novice designers. Amongst industrial design students, makerspace participation also relates to lower design anxiety[29], which in turn likely translates to greater learning outcomes, as anxiety antagonizes one's ability to learn [30]. Anxiety is inversely related to self-efficacy [31, 32], self-efficacy being the extent to which one believes that they can produce a certain outcome [33]. Higher design self-efficacy has also been found to be correlated with making experience and makerspace participation. [10, 11, 14, 34-37].

1.2 Makerspace Motivations

The origins of the university makerspace can be traced back to hacking [38]. Hacking is an informal and unstructured design approach that emphasizes developing quick and simple solutions to design problems. The hacking movement was initiated in the sphere of computer science, with open source software and DIY hobbyists developing clubs to pursue their passions for computer engineering, independent of the conventional classroom [39-41]. Following the hacking trends, makerspaces have become widely adopted throughout academia. Their scope has expanded to include a wide array of tooling that meets the diverse interests of students [42].

Courses encouraging makerspace have also become a powerful motivator to use makerspaces [14, 15, 43]. At a dozen MIT makerspaces for instance, 43% of undergraduate students cited using the makerspace for class, compared to 18% and 15% citing hobbies and research, respectively [44]. Course involvement may also have lasting impact on makerspace participation. Students who were initially motivated to use a makerspace by course requirements were likelier to be involved with the space at the end of the semester compared to students who had no course mandate [15]. Course related makerspace use has also shown to be related to better academic performance [14]. Students using the space voluntarily at times reported having less anxiety than their peers who only used the space for coursework, or did not use the space at all [35]. In turn suggesting that while course required makerspace is certainly useful, it may not be a perfect solution for ideal making outcomes.

1.3 Makerspaces & Belonging

A sense of belonging has been identified as a critical factor that can motivate or deter students from using a makerspace[22, 45]. Engineering students who do not use the space have been documented as having less self-efficacy, and a weaker sense of belonging, with this often being particularly impactful for women and other URMs [36, 45]. While classwork, research, or being invited by a peer have demonstrated utility for motivating space use, they have not been equally effective for women and URMs who still face significant barriers that deter makerspace participation [22]. Despite efforts to promote minority representation throughout STEM, women and other URMs are still underrepresented in engineering programs [46] and in makerspaces [35, 47, 48]. University and K-12 makerspace users both commonly suggest making changes to makerspaces to help foster an environment that is welcoming, accessible and fun [49, 50]. Extending invitations, holding open houses or workshops specifically for women have been reported to be valuable for introducing students to makerspaces, especially early in academic careers [21, 48]. For many students, especially women, a peer inviting them to use the makerspace often makes the difference that gets them involved in the space [15, 21, 43].

1.4 Data for Makerspace Research

Previously, research on makerspaces has predominantly taken three different approaches for data collection: 1) student interviews regarding experiences in the makerspace, 2) use of student ID swipe systems integrated into makerspaces for scheduling and inventory purposes, 3) and survey-based approaches [51-54]. Qualitative interviews provide insightful data regarding students experiences [34, 52]. Interviews, however, are particularly time-consuming and generally yield very low sample sizes. As a result, qualitative data is difficult to generalize as many students' voices are not heard and those whose are sampled may not be indicative of their peers. Interviews are highly effective for an in-depth understanding of the experiences of a small group of students. They can also easily be followed-up with research methods that allow for larger sample sizes.

Another common mode of data collection for makerspace research involves capitalizing on swipe-in systems already in use [51-53]. Such systems validate that students are authorized to use a certain space or tool, and can also be used to schedule a timeslot to use a popular tool ahead of time. Swipe in systems vary drastically from program to program. Swipe in data is also not always suitable for comprehensive makerspace analysis as the system may not track tool use for all tools in a space. For example, if the swipe in system does not capture most tools in the space or is only used for tools where safety is a concern for instance, there will not be comprehensive data about how the space is used. A swipe system where all tools require some type of swipe-in by students would be extremely accurate in theory, but this is not the case in practice. Students have been observed swiping in for each other when in a large project group resulting in the use of a tool being underrepresented [51, 53]. Making processes also rarely follow initial plans and as a result the tools students indicated they intended to use often changes midway through their making session. For swipe-in systems that only check students in, these deviations may not be reflected.

Survey based methods offer a common ground between the detailed and insightful data of ethnographic work and vast amount of data provided by swipe-in based methods. While swipe system-based methods typically only report the tool used and the duration of that use, surveys can collect data with greater scope, however they have been documented to suffer the shortcomings with respect to accuracy and bias in the data collected [54-57]. Surveys about makerspace use conventionally are conducted as reflections on past makerspace experiences: memory unfortunately has limited reliability. Memory based data in turn often results in inaccurate overestimates of how often students used the space or certain tools [57]. Surveys are often not taken seriously by participants as they can just "click through" answering inaccurately or erroneously [58] with one study noting a 'click-through' rate of 23.7% on an email based survey [59]. This inaccuracy may be improved by shortening the length of surveys [58] but depending on the scope and subject matter of the survey this is not always possible. Furthermore surveys can be paired with observational data to verify survey accuracy [60], although this method is resource intensive, and not always possible depending on survey distribution.

Surveys are almost always optional voluntary activities. Academic settings often mandate this to avoid placing undue stress on students, leading to a nonresponse bias where certain segments of a population do not respond to the survey, and are not reached [61].

Often times, the portion of a population that is most often responding are those who are most or least satisfied with the subject matter of the survey, as they are enthusiastic about voicing their opinions. Unfortunately, the more typical opinions are more often the non-responders, leading to skewed data. In a variety of survey formats and contexts, women have been found to have significantly higher response rates than men [62-64]. While women's experiences in makerspaces are an important point of investigation in this work, this phenomena could lead to a potentially biased sample.

While surveys do entail their fair share of limitations, they have demonstrated considerable value for providing insightful information in a wide variety of fields, makerspaces included [47, 65, 66]. In addition to this detail, they are well suited for reaching wider audiences than most qualitative methods, making them a promising methodology for makerspace use characterization efforts.

METHODOLOGY

1.5 Data Collection

Tool use data was recorded to better understand how makerspace use, specifically which tools students are using and how often they use them. This data in conjunction with demographic and academic information, as well as a knowledge of students' past making experiences, may also provide a more thorough understanding of what makerspaces are being used for and by whom. A characterization of a makerspace's use can be compared against other makerspaces, providing insight into how makerspace design and management influences its use.

Surveys were used to collect this data as they are well suited for collecting large amounts of nominal and discrete data and can be conveniently distributed via QR codes or other modes of electronic communication. The use of surveys however poses three challenges. First, longer surveys that cover the breadth of information being collected in this work often frustrates or bores participants leading to lower quality data [67]. Second, considering how unreliable memory is, it can be difficult to expect participants to record their tool use history accurately, especially when asking them to recall tool use over extended periods of time like a semester [55]. Lastly, in the making process one's initial plan is not always executed as intended. Certain tools may be unavailable, or a student may realize there are better tools to use. These deviations represent interesting data but may be difficult to capture with conventional reflection surveys. Accordingly, two surveys were developed to address these shortcomings: An "Entry/Exit" and "End-of-Semester" survey. These Entry/Exit surveys are much briefer in comparison to the End-of-Semester surveys, taking roughly 3 minutes to complete as opposed to 20. These surveys are kept brief to deter partial or inaccurate responses and promote survey recruitment that may be adversely affected by longer survey length. Entry/Exit surveys also may avoid memory related issues as they are conducted immediately before and after a participants' use of the makerspace. Furthermore, differences between entry and exit survey results may capture departures from students' initial plans, potentially highlighting barriers in a makerspace or common difficulties students may have with certain tools. Entry/Exit surveys' brevity is achieved by solely including questions regarding tool use and not the demographic, academic, and added tool usage questions included with the End-of-Semester survey. These surveys were validated with observational data, with five students recruited to complete the Entry/Exit surveys while being observed by a researcher. The observer made note of what tools students used while in the space, comparing these notes to students' Entry/Exit survey results to provide insight into how accurate students are reporting the tools they used. These results are discussed in section 1.7, but corroborate concerns that students initial plans when entering the makerspace can deviate from what they actually do.

The End-of-Semester survey serves as a final reflection to collects tool use data and academic/demographic information. This additional data allows for richer analysis, as tool use can be analyzed by various factors of interest like gender, major and so on. Lastly, the validity of tool use results from the End-of-Semester surveys can also be confirmed by comparing them against tool use results from the Entry/Exit survey. Entry/Exit survey data proved to be consistent with End-of-Semester results. Accordingly, Entry/Exit data represents a relatively minor proportion of the data presented in the results section.

Entry/Exit surveys were also catered to observe potential changes between what tools students anticipate they will use, and those that they do end up using, thus collecting data without the shortcomings inherent to longer surveys as previously mentioned. Making is rarely a linear process, any number of events from parts breaking, to a change in the available tools can cause deviations in the tools and activities a student uses while in a makerspace. Capturing tool use data immediately before and after a student uses the space allows for a comparison between entry results and exit results that can highlight any such deviations. Due to time constraints and limited sample sizes individual students deviations from plans was not analyzed. Appendix D: Planned vs. Executed work, highlights this and any other data collected (for both surveys) that was not analyzed due to various constraints.

To facilitate participation for this survey, QR code embedded flyers are placed at the entrances and exits of the makerspaces. After scanning these flyers with their mobile phones, participants were directed to an informed consent form and then the Entry/Exit survey. Before any tool use data is collected, participants are asked to indicate whether they are entering or leaving the space, as well as for basic identifying information (name, email, student ID Code) to allow their entry and exit responses to be paired.

To collect tool use data, participants were first asked which general categories of tools or activities (e.g. 3D printers, metal tools, Wood tools, Studying/Hanging Out/ Meeting with a Group) they planned to use or did use in the space. After selecting the categories they used, participants are asked which specific tools they used and how often they used them only for the categories they selected. This format is used to effectively shorten the length of the survey and promote more accurate responses. Displaying the many tools in a makerspace all at once would require excessive scrolling on participants' mobile phone screens, which would likely translate to frustration, and in turn incomplete or inaccurate responses.

This multiple-choice format is also helpful for improving response accuracy and streamlining data analysis. If participants were just asked to type in which tools they used, this would be cumbersome to do on a phone and also could result in participants may entering erroneous answers, such as reporting they used tools that aren't included in the makerspace or referring to a specific tool with a generic name (Calling a table saw or band saw just a "saw" leading to ambiguity) and being asked to type in which tools is cognitively more difficult leading to worse recall and lower response rates. Given that many 3D printers look very similar and students who use them may not be familiar with their specific make/model, pictures were included next to answers to avoid confusion and ensure accurate responses. Furthermore, an option "3D Printer -Unsure" was included for students who still struggled to identify which 3D printer they used, so their use of 3D printers was still noted.

To ensure that every participant completes both an entry and an exit response each time they participate, Qualtrics automatically sent a follow-up email several hours after a participant completes an entry response, requesting that they complete a corresponding exit response if they have not already done so. These surveys are very brief, typically taking 3 minutes to complete. For each completion of both an entrance and exit response, students were paid $1 with a limit of $75 per semester. A full copy of this survey can be found in Appendix A.1.

While the Entry/Exit surveys provide valuable insights into tool popularity and how students' tool use may differ from their intentions, they do not speak towards the various factors that may influence tool use. The End-of-Semester survey seeks to fill that gap by surveying students in greater depth than the Entry/Exit surveys, making note of the intersection between tool use and student motivations, previous making experience, demographics, and other factors.

To understand what factors influence makerspace use and to what extent these factors dictate how students use the space, five categories of data were collected by End-of-Semester surveys:

- Makerspace Experience
- Tool Use in the Past Semester (similar to the Entry/Exit survey)
- Frequency of Said Tool Use
- Tools Previously Learned
- Demographics

The makerspace experience section assesses how extensively students have used the makerspace in the past as well as asks students for what purpose they have used the makerspace, whether it be for class, personal hobbies or other motivations. Questions in the makerspace experience section are multiple choice, with a final multiple choice answer option always being an open-ended text response, to provide students the opportunity to indicate answers that were not anticipated when designing the survey.

End-of-Semester tool use data serves as the predominant metric for assessing how various factors influence makerspace use. This tool use data is collected in the same way as it is on Entry/Exit surveys, where students are first asked which general categories of tools they used, and subsequently asked which specific tools within those categories they used. Unlike the Entry/Exit Surveys however, students were asked not only whether or not they used a tool, but how many times they used the tool throughout the semester. These estimates proved to vary drastically, raising concerns about the accuracy of students responses. As a result these results are not reported, but may be found in Appendix E: Miscellaneous Figures.

Past making experiences and learning experiences may very well have significant influence on how students interact with the space. Accordingly, the tools previously learned section documents which tools students have learned prior to the current semester, and whether they learned this tool in a previous semester or prior to college altogether. Lastly, demographic information is collected to inform the current understanding of how race, gender, factors play into students' makerspace experiences. Responses from participants who omitted answers to essential tool use questions, specifically questions Q126 and Q136 in appendix section A.2, were discarded.

End-of-Semester Surveys were distributed in Fall 2019, Fall 2020, and Spring 2021. Important to note is that the End-of-Semester Survey collected in Fall 2019 was a pilot survey to inform the broader research effort that thesis contributes to. As a result, the Fall 2019 End-of-Semester survey was only conducted at one of the two schools, which shall be referred to as School A. This survey also collected data for a different study on a similar topic, and as a result was considerably longer than subsequent survey iterations. Furthermore, students for this initial pilot survey were paid $40 as opposed to $20 which may have led to different numbers of participants recruited, as well as the quality of data. These implications will also be further deliberated in the Results & Discussion.

To capture a broad audience these surveys were distributed to courses with high makerspace involvement. At School A, this consisted of the following: introduction to CAD, advanced CAD, materials/manufacturing, ME senior design, manufacturing methods, and EE senior design. At School B, these courses consisted of an intro CAD course, and ME sophomore design and ME senior design. A lengthier discussion of these courses can be found in Table 3 in the Research Sites section. Recruitment from these classes was done for the Fall 20 and Spring 21 data collection periods. During Fall 19 recruitment was only done in Senior ME Design. Students were recruited from these classes via email, course website announcements, and in-person announcements at the beginning of course lectures. In-person or virtual class announcements were performed at the convenience of the instructor 2-3 weeks before the end of the semester. Surveys were electronically distributed during finals week, as students are still checking their emails during this period but are perhaps not quite as busy as they are during the reading period immediately prior to finals week. Additionally, in a given round of data collection, any student who had completed any survey in any prior instance of data collection was invited to participate, so long as they had not graduated.

Entry/Exit Survey data were collected at both institutions in the Fall 20 and Spring 21 semesters. These surveys were available as long as the makerspaces they pertained to were open, which typically started a week or so prior to the start of the semester, and ended during students' reading period before finals week.

To reiterate, all of the data described in the above section was collected but not all was analyzed due to time, sample size, or other constraints. Appendix D lists out any data collected that was ultimately not analyzed.

1.6 Research Sites

The work presented in this paper was conducted at two universities in the southern United States. Both schools are known for the STEM programs, with School A being a large, more comprehensive university, while School B is a medium sized technical university that mainly offers degree programs in STEM. Table 1 highlights the colleges found at both Schools. Similar colleges are shown next to one another, but note that degree programs offered vary considerably between institutions for similar colleges.

Table 1: Colleges at Schools A & B

Colleges at Schools A & B	
School A	School B
Agriculture & Life Sciences	
Architecture	Design
Arts & Sciences	Sciences
	Liberal Arts
Business	Business
Dentistry	
Education & Human Development	
Engineering	Engineering
	Computing
Engineering Medicine	
Government & Public Service	
Law	
Medicine	
Nursing	
Performance, Visualization & Fine Arts	
Pharmacy	
Public Health	
Veterinary Medicine & Biomedical Sciences	

Both schools have approximately 4 and 6 makerspaces, with each including a main makerspace that serves as the main mechanical engineering (ME) makerspace. While primarily used by ME students, these two makerspaces are open to students of all majors. These spaces are also not the only making facilities available to ME students; other making facilities are described in Table 2. This table may not be entirely exhaustive of all making institutions, at School A especially. Makerspace is not a commonly used phrase at School A, making it difficult to identify such spaces. Furthermore, what exactly defines a makerspace may be ambiguous, as there is a broad spectrum of technical facilities that enable different types of making, from conventional makerspaces to graduate research labs. Accordingly, this table excludes more niche research and manufacturing facilities that serve smaller populations, and instead focuses on STEM facilities that are open to a broader student body and offers more conventional makerspace tooling (e.g. 3D printers, machining tools, woodworking, etc.). Even still, there may be makerspaces at both Schools that were not found or reported on due to naming differences or other obscurities.

While whether Table 2 is entirely exhaustive is not completely certain, it does seem that School B has a greater number of dedicated makerspaces than A, with most engineering disciplines offering their own proprietary makerspaces. There is considerable overlap in tooling at these spaces, resulting in makerspaces competing for students. School A has less competition from alternative makerspaces, as there are fewer major specific makerspaces. As a result, School A's makerspace may play a larger role in its respective engineering college and draw more students to it than School B's. This may result in greater diversity with respect to majors at School A, as there may be relatively fewer non-ME makerspaces, in turn driving non-ME students to School A's predominantly ME makerspace.

Total sample sizes for the End-of-Semester survey included 179 and 139 participants from Schools A and B, respectively. Entry/Exit surveys yielded 252 Entry responses and 239 Exit responses at School B, due to time constraints and redundancy Entry/Exit results from School A were not analyzed. This End-of-Semester survey took roughly 20 minutes for participants to complete, for which students are compensated with $20 Amazon gift cards. A full copy of this survey can be found in Appendix A.2 End-of-Semester Survey Example with All Survey Logic Annotated.

Table 2: Makerspaces and Similar Facilities at Schools A & B

SCHOOL A	
Makerspace	**Capabilities**
"School A's Makerspace"	3D Printing, Metal tools, CNC/manual machining, Wood Tools, Laser Cutting, Electronics tools, water jet, Soft Material tools, Welding, hand tools
Industrial Design Machine Shop	Machining Tools
Biomedical Engineering Makerspace	Lathe, Getting Help from Instructors
3D Printing Lab	3D printing, 3d printing hand tools
SCHOOL B	
Makerspace	**Capabilities**
"School B's Makerspace"	Wood Shop, Metal Shop, Laser Cutting, 3D Printing, Electronics, PCB Fabrication, Water Jet, Wood CNC, Metal CNC, Crafts, Bike, Welding, CAE Helpdesk
Electrical and Computer Engineering Makerspace	Electronics, PCB Fabrication, Machine Shop, Laser Cutting, 3D Printing, Plasma Cutter, Crafts
Aerospace Makerspace	Wood Shop, Laser Cutting, 3D Printing, Electronics
Biomedical Engineering Makerspace	Laser Cutting, 3D Printing, Vacuum Forming, Resin Casting, CNC/Manual Mill & Lathe
Material Science and Engineering Makerspace	Material characterization, processing, and measurement tools
Mechanical Engineering Machine Shop	Conventional Machining Tools & EDM
Design/Architecture Makerspace	Wood Working, Soft Material Tools, Welding, Hand Tools, CAD Resources

In addition to less makerspace competition, School A's makerspace is a substantially larger facility at 61,000 sq. ft [68]. On paper, School B's makerspace pales in comparison, occupying 5482 sq. ft (from CAD drawing of the space). Despite the disparities in scale, the tooling present and the types of collaborative activities that occur at both spaces are very similar, with both facilities containing the following categories of tools: 3D printers, metal tools, laser cutter, paint booth, soft material tools, hand tools wood tools, electronics tools, work areas, getting/giving help, studying/hanging out/meeting with a group. Most of these differences in physical area are made up for by a more extensive machining facilities at School A, whereas School B has another separate machine shop detached from the makerspace. Furthermore, School A has more large areas dedicated for group work, that also inflate this large area figure.

Between schools there are minor differences in tooling, mostly with respect to brand or specific model of tool. Beyond these superficial differences, any major tooling disparities can be found in Table 3(given the number of tools present at both schools, this table only shows tools that are unique to a school for brevity). For a detailed and complete list of all tooling at both schools, see Table 17 in Appendix C.

Table 3: Unique Tooling: Tools Present at Schools A & B that the Other School Does Not Have

School A	School B
Metal 3D Printer	Carbon Fiber 3D Printer
Hydraulic Press	Polishing Wheel
Electrical Discharge Machining	Vinyl & Paper Cutter
Dedicated Work Tables for Extended Projects	Embroidery Machine
Mobile HDTV	Foam Cutter
	Planer

While there are noteworthy tooling differences, the tools/activities found in these spaces are far more similar than not. A subtle difference between these schools however is in their management styles: School B is predominantly run by student volunteers overseen by a committee of faculty at this institution, whereas School A has student employees as well as a conventional shop staff. Workers at both schools receive basic first aid training as well as fire safety training focused on locating nearby escape routes. Student volunteers at School B must complete a tool training program that covers all major tool groups in an effort to ensure volunteers are well equipped to aid students and identify safety hazards. Student employees while not required to take training before working in the space, have often received training as this group typically consists of highly motivated makers.

Despite these training and pay differences the roles of student workers at both schools are very similar. Volunteers spend their time in the space helping students with projects, mentoring and teaching students how to use equipment, as well as ensuring the space is used safely by all members.

Differences in makerspace worker population sizes may be influential as well. At School A shifts are distributed so there are typically 4 student employees working in the makerspace, with 2 full time staff present as well. The number of student volunteers varies widely at School B, with a similar average of 4 makerspace volunteers at a given time, but no full-time staff. More volunteers are scheduled at busy times at School B, with as many as 9 volunteers being scheduled on a busy afternoon. Makerspace A also serves a slightly larger population with a typical afternoon rush consisting of 40 students, compared to 30 at School B. At both schools this can easily surge up to 60 students during the final weeks of the semester. For the bulk of the semester however, it may be the case that the ratio of facilitators to makers at School B is greater. While this may lend itself to greater collaboration and engagement from students in the space, too many facilitators could lead to an environment where students feel they are being hovered over, in turn stifling making.

At both institutions there are several courses that require or are heavily associated with makerspace use. Disparities between how often tools are taught as well as what kinds of tools are taught may have a significant influence on how each respective makerspace is used. Making related classes and the level of making involvement associated with these classes is shown below in Table 4.

Table 4: Classes Related to Participation in the Makerspaces

SCHOOL A		
Course Description	**Tools Taught/Required**	**Tools Commonly Used**
Computer Aided Engineering	3D Printing	Hand Tools
Advanced Computer Aided Engineering	Welding, Bending	Water Jet, Band Saw, Mills
Materials/Manufacturing	Lathe, Mill, Band Saw, Hand Tools	
Manufacturing Methods	3D Printing, CNC Lathe,CNC Mill	3D Printing,CNC Lathe,CNC Mill
Mechanical Engineering Senior Design		3D Printers, Laser Cutters, Water Jet, Wood Router
Electrical Engineering Senior Design		Depends largely on project
SCHOOL B		
Course Description	**Tools Taught/Required**	**Tools Commonly Used**
Computer Aided Engineering	3D Printing	
Mechanical Engineering Sophomore Design	Laser Cutters, 3D Printers, Wood Tools	Electronics, Hand Tools
Mechanical Engineering Senior Design		3D Printers, Electronics, Laser Cutters, Wood Tools, etc.

Course names are changed to preserve anonymity of both institutions, but still summarize the general topic of said courses. While School A has more making related courses, the number of classes associated with making, there are several notable similarities in making-related curriculum at both institutions. Both schools have a CAD course for newer (typically 1st or 2nd year) engineering students , as well as a senior design course, for which the tools required and/or are commonly used are consistent between schools. For intermediate level engineering courses however, there are notable differences. Namely, there are more manufacturing-oriented tools like machining and metal working tools being taught at School A in the “Computer Aided Design” and “Materials/Manufacturing” courses. Alternatively, School B's "ME Sophomore Design" emphasizes many of the tools that synergize with a CAD and rapid prototyping like 3D printers, laser cutters, and wood tools more so than School A. Whether or not the differences detailed in Table 4 yield a significant difference in how the space is used by students will likely depend on the proportions of students that are using the makerspace for class.

RESULTS & DISCUSSION

1.7 Data Validation

Entry and Exit responses for Entry/Exit surveys at School B are displayed in Figure 1 as can be seen in the figure, the entry and exit data are very similar. Chi-squared tests are conducted to determine whether there are significant differences with respect to the frequency with which students use tools between students completing the entry portion of the survey and students completing the exit. For all groups there are no significant differences, indicating that the tools students plan on using when first entering the space, are similar to the tools they plan on using.

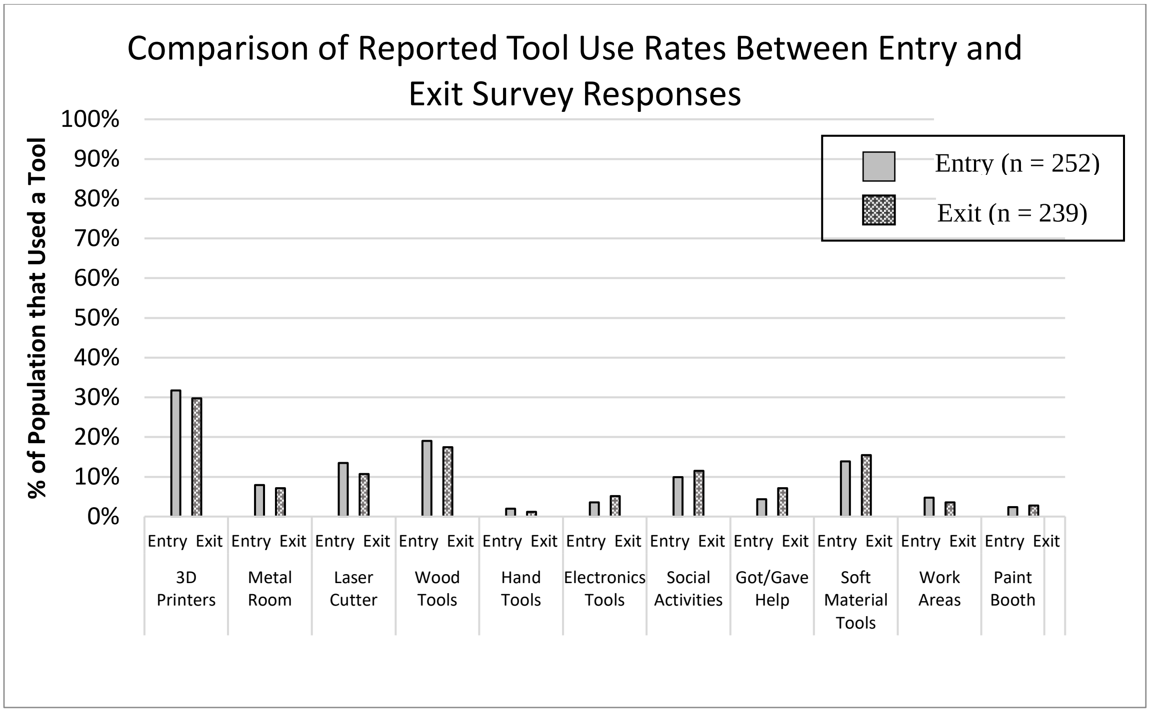

Figure 1— Tool Use Rates of Entry Responses and Exit Responses at School B

Table 5: Chi-Squared Results Comparing Tool Use Rates Between Entry Responses and Exit Responses at School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n	486	486	486	486	486	486
df	1	1	1	1	1	1
χ^2	<0.01	0.01	0.42	0.17	0.11	0.73
P-Value	0.94	0.92	0.52	0.68	0.74	0.39
Tools	**Handheld Tools**	**Wood Tools**	**Electronics**	**Work Areas**	**Got/Gave Help**	**Social Activities**
n	486	486	486	486	486	486
df	1	1	1	1	1	1
χ^2	0.37	<0.01	1.11	0.25	2.39	0.75
P-Value	0.54	0.95	0.29	0.62	0.12	0.39

General trends seen in the results of Entry/Exit surveys are fairly consistent with those of the End-of-Semester surveys depicted in Figure 3. Tool use rates are higher in the End-of-Semester survey results, as this data represents tool use over an entire semester and not individual making sessions. Results from both surveys note similar trends, like that 3D printers and Wood tools are some of the more popular tools at School B. There are interesting differences as well, like that metal tools and laser cutters have a trend of relatively less tool use as indicated by Entry/Exit surveys when compared to End-of-Semester surveys. This may be because students use these tools relatively few times throughout the semester, so they are not captured in Entry/Exit surveys as often as End-of-Semester surveys. Data concerning how many times students used tools was collected by End-of-Semester surveys, and this data could potentially cast a light on whether these disparities between Entry/Exit surveys and End-of-Semester surveys are because of differences in tool use frequency. Unfortunately, it was found that student estimates of how often they used tools are likely inflated, and are very heavily skewed, making this comparison impossible. Examples of this tool frequency for reference data can be found in Appendix E: Miscellaneous Figures.

Table 6: Entry/Exit Survey Accuracy Results from Observation

Participant	Entry/Exit Accuracy	Observation/Exit Accuracy	Observation/Exit Accuracy Adjusted*
1	80%	50%	100%
2	100%	50%	100%
3	67%	100%	100%
4	0%	100%	100%
5	33%	50%	50%
Averages	70%	63%	90%

Observing Entry/Exit survey participants while they used the makerspace (In-between completing the entry and exit portions of the survey) further demonstrated that students are accurately reporting the tools they used and activities they engaged in. Of the 5 students observed, it was found that tools/activities students indicated on their Entry surveys were also found on their exit surveys 70% of the time. Considering students plans may deviate after completing the entry survey may explain this. Students Exit responses however were only 63% consistent with the researchers observations, raising concerns about the accuracy of students responses. During this observation it was noted that it was often difficult to differentiate between social or collaborative activities. The ‘Observation/Exit Accuracy Adjusted*” column in Table 6 represents how consistent students Exit survey results were with that of the observer, when given the benefit of the doubt for social and collaborative activities. Social and collaborative activities were not excluded entirely, but if a student reported they helped another student, while the observer assumed they were meeting with a group, they were given credit. With this method it was noted students Exit results were very consistent with the observations, ameliorating concerns about response accuracy. Tabulated responses from participants comparing which tools they reported or were observed as using can be found in Appendix B. Results from Observing Entry/Exit Survey Participants.

1.8 Differences in Makerspace Use Between Schools A & B

There are considerable differences between Schools A and B that may have significant influence over how makerspaces are used at these universities, as discussed in the Research Sites section. To reiterate, the disparity of making related classes that utilize these makerspaces, and the tools these classes teach varies substantially, and it is postulated that this may change the rates at which tools relevant to these classes are used within the makerspaces, and may even effect use rates for unrelated but similar tools.

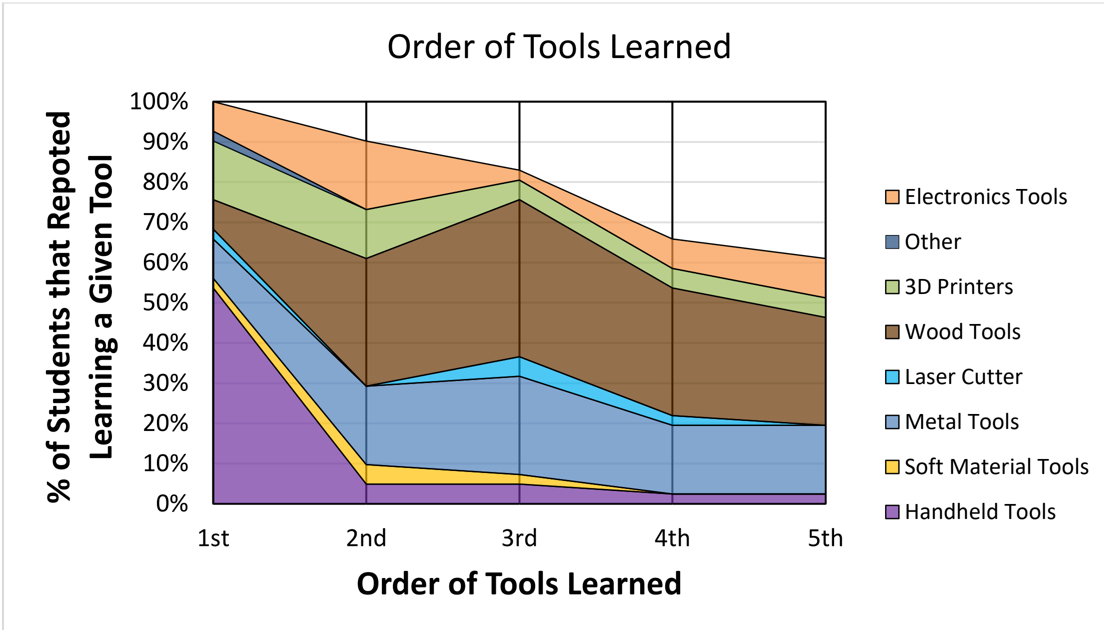

Figure 2- Order of Tools Learned by Students at School A (n=61), Fall 2020

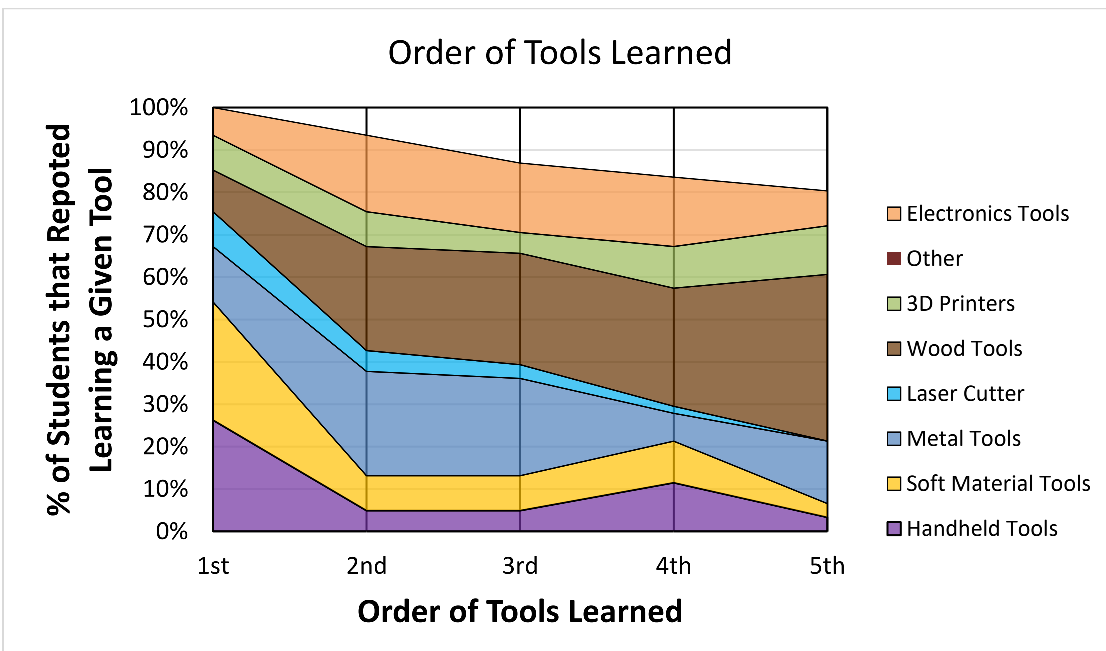

Figure 3- Order of Tools Learned by Students at School B (n=41), Fall 2020

Figures 2 and 3 shows the progression students go through in the makerspace by asking students to recall the first 5 tools they learned. The question this chart is based on is a drag and drop style question with two bins: a “Learned Tools” bin and a “Don’t Know How to Use” bin. This question reads “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.”. Figures 2 and 3 shows only general categories of tools as opposed to individual tools. There are over 80 different tools students may enter, and there is also the option to provide an answer not listed. Accordingly, showing all tools makes for data and graphics that are difficult to interpret. As a result, tools are grouped into the categories shown. This grouping is conducted for all future charts and analysis in this work as well. Figures 2 and 3 contain data from Fall 2020 only, the Spring 21 data for School A did not collect hand tools unfortunately, due to a survey error. The list of individual tools that comprise these groups can be found in Appendix C. Complete Tooling Differences Between Research Sites

At both schools, hand tools represent a major portion of the first tools learned by students. This indicates these are probably tools that nearly all makerspaces should have and potential entry points for students. Wood tools represent a large proportion of the 2^{nd}-5^{th} tools learned by students as well, more so than the 1^{st} tool learned. Wood tools are commonly used for prototyping efforts by introductory engineering courses, so it may be the case that students are transitioning to more advanced tools in the wood room to meet course requirements.

The order students learn tools is not entirely the same at these two schools either. Overall, students appear to be learning more tools at School B. In Figure 2 100% of students indicate learning at least one tool, but response rates subsequently drop off at both schools. This rate drops off faster for School A, with only 61% of students reporting learning a 5^{th} tool compared to 79% at School B. Prior literature has noted that makerspaces and makerspace training programs can have turnover rates as high as 50% a semester [53]. While the data in Figures 2 and 3 only represents that of one semester and does not speak to semester-to-semester retention, it does indicate that many students are not learning many tools, and there are still many opportunities to improve student learning in makerspaces.

Soft Material Tools are a commonly learned tool at School B initially, but not at A. At School B, a smaller proportion of students used the makerspace for class (which will be discussed at greater length in section 1.10). Considering soft material tools are not associated with course making requirements at either school, it may be that students who aren't using the space for class are relatively more inclined to explore soft material tools for extracurricular projects, leading to more soft material tools being learned at School B.

Differences in course training requirements may influence these learning habits as well. Laser cutter use does not represent a large proportion of the tools learned in either makerspace, but is considerably higher at School B, potentially because courses at this School place a greater emphasis on laser cutters than School A does, as seen in Table 4. That being said, at School B students have the option to virtually submit laser cutting and 3D printing jobs and have those jobs completed by makerspace volunteers, so to what extent students are actually learning to use these tools themselves is ambiguous.

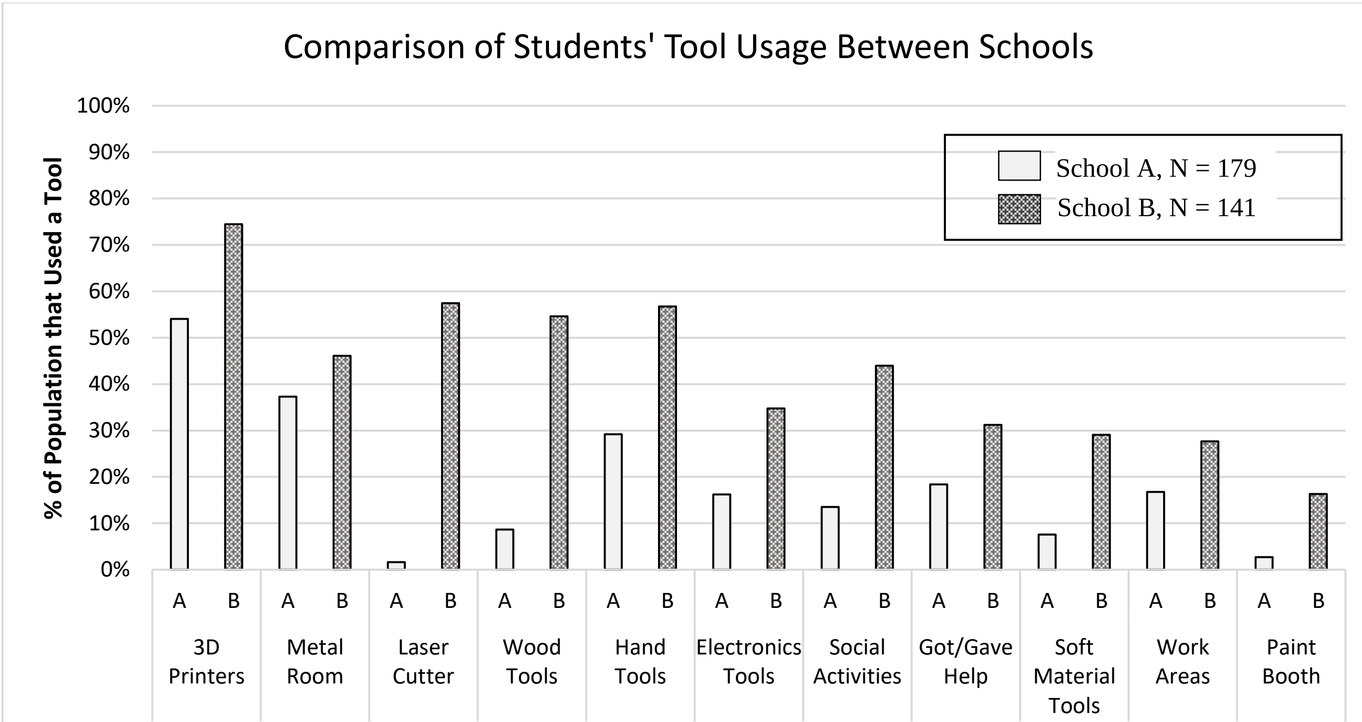

Figure 4 — Tool Use Rates at Schools A & B, Fall 2020 & Spring 2021

Table 7: Chi Square Results Comparing Tool Use Rates at Schools A & B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Soft Material Tools	Hand Tools
n	320	320	320	320	320	320
df	1	1	1	1	1	1
χ^2	11.85	1.85	126.72	18.05	25.04	22.88
P-Value	<0.01*	0.17	<0.01*	<0.01*	<0.01*	<0.01*
Tools	Wood Tools	Electronics Tools	Work Areas	Got/Gave Help	Social Activities	
n	320	320	320	320	320	
df	1	1	1	1	1	
χ^2	79.80	13.73	4.94	6.38	35.87	
P-Value	<0.01*	<0.01*	0.03*	0.01*	<0.01*	

Figure 4, shows that students at School B generally use a greater variety of tools than those at School A. While it is the case that students at School B have generally higher tool use rates for most tools, these margins between schools A and B are not constant at a tool-to-tool level. The tabulated Chi-Squared results in Table 7confirm this, with significant results indicated by an asterisk. Metal tools are used at a statistically equivalent rate between schools for instance, and are even trending slightly higher at School A despite generally lower tool use rates at this school. Conversely, there are some tools like the laser cutter and wood tools where the discrepancy between use rates is significantly more pronounced than it is for other tools.

One factor that may in part explain this general discrepancy in tool use rates is the makerspaces' management styles. Unlike the staff-led model found at School A, School B has a student-based model with relatively more student facilitators as described in the research sites section. Previous literature has identified that authority figures in makerspaces can have a major impact on student participation [69]. In a similar vein, a major modes through which students are introduced to makerspaces is from invitations from their peers [21]. If it is the case that School B has relatively more student facilitators than School A this may in turn result in students learning a greater number of tools, as there are more facilitators that can teach students tools. Additionally, every student facilitator in the space is also one more person that can invite their friends which could lead to more participation.

The many factors that dictate these discrepancies will be discussed in the following subsections within the Results & Discussion sections (subsections 1.9, 1.10, 1.11, 1.12), but that these discrepancies both exist and vary from tool-to-tool suggests that differences between these makerspaces, whether deliberate design decisions or contextual accidents, can have a significant impact on how students use the space.

1.9 Effects of Covid-19 on Makerspace Use

The Covid-19 Pandemic has had substantial influence over the tools students used and how often they used them at both spaces. This influence can be seen at School B in Figure 5 below with data from Fall of 2019 compared to a dataset encompassing tool use during Fall 2020 and Spring of 2021.

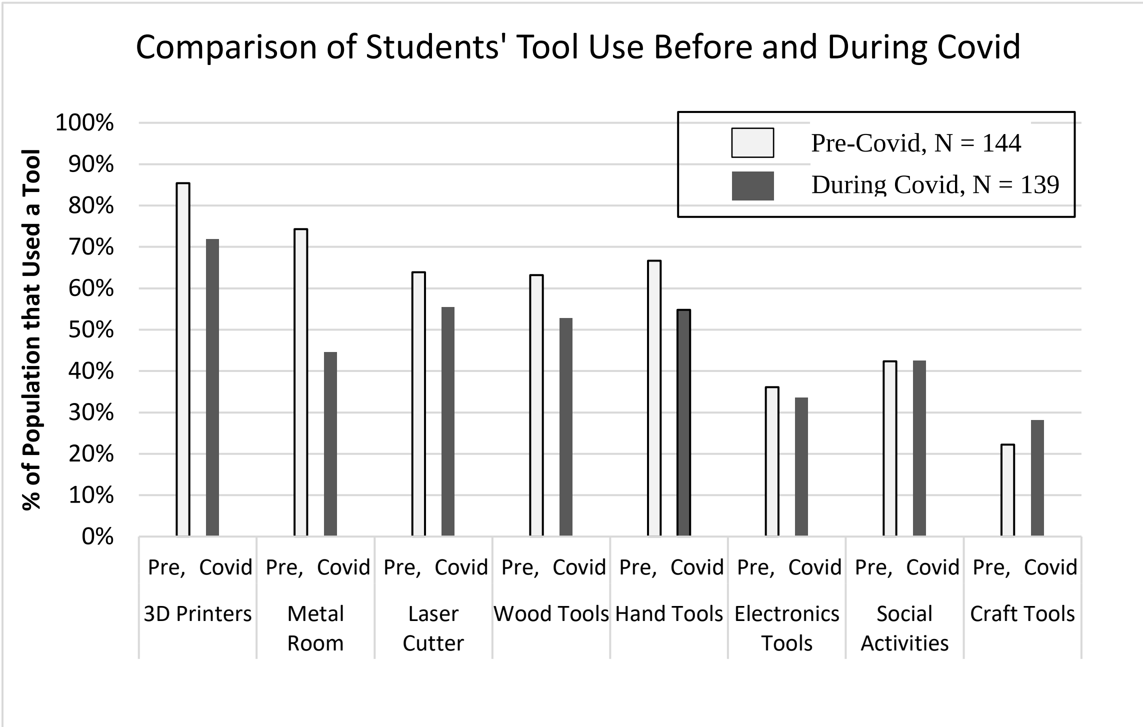

Figure 5 — Tool Use Before & During Covid at School B

Generally, Covid and the regulations that came with it have seen a modest decline in tool use rates at School B.

Table 8: Chi-Squared Results Comparing Tool Use Rates Before and During Covid at School B

Tools	3D Printers	Metal Room	Laser Cutter	Wood Tools	Hand Tools	Electronics Tools
n df χ^2	283 1 11.65	283 1 32.18	283 1 4.24	283 1 7.07	283 1 4.78	283 1 0.85
P-Value	<0.01*	<0.01*	0.04*	<0.01*	0.03*	0.36
Tools	Social Activities	Got/Gave Help	Soft Material Tools			
n df χ^2	283 1 0.02	283 1 34.17	283 1 0.34			
P-Value	0.89	<0.01*	0.56			

Table 8 shows that some of the more seldom used tools like electronics tools and soft material tools demonstrated no change as a result of Covid. Considering that use rates for these tools are already fairly low, it may be the case that these tools are mostly used for niche applications by highly motivated students that would be difficult to deter from using these tools. Additionally, the sample of students that used these tools is low adversely effecting analysis for these tools.

Social activities like studying/hanging out/meeting with a group proved to be more resilient to the effects of Covid regulations than most other tools and activities as well. Considering students' general fear of Covid, student capacity limits, as well as that these social activities can be done in other university spaces or even virtually, one might expect these social activities to stop completely in the makerspace, but this proved not to be the case. Students who use the space for social purposes may be more comfortable with these spaces or may have integrated them into their routine. They may also be students that are so highly motivated with respect to making that they cannot be realistically deterred from using the space. At least not with the current restrictions and the extent to which they are enforced.

A pre/post comparison of the effects of Covid on tool use at School A is unfortunately not possible. The ‘pre’ data shown above in Figure 5 originally served as the pilot data for this study, and as a result was only collected at School B. The effects of Covid-19 may be evident in School A’s generally lower participation shown in Figure 4. School A imposed more restrictive measures to address the Covid-19 pandemic as discussed in the research sites section. Without data collected after Covid restrictions are lifted from School B’s makerspace however it will be impossible to concretely make this claim.

Accordingly, this greater diversity of tools used at School B as seen in Figure 4 may in part be due to these relatively relaxed restrictions. While regulations at School B were stricter, there is also considerable evidence that these regulations were not universally enforced or followed. 14% of students at School A for instance studied/hung out/met with a group, despite these activities being prohibited in this space. In addition, students at School A may have been less inclined to report engaging in social or other non-making activities given these activities were ‘not allowed’, so the extent to which these Covid restrictions has influenced the space remains, for now, ambiguous.

1.10 Class Involvement & Makerspace Use

The role of class involvement in makerspaces is largely in flux as capstone classes and introductory engineering courses are rapidly evolving to integrate these spaces into their curriculum. In trying to develop a more comprehensive understand of how makerspaces are used it is necessary to investigate the impact different types of making-related courses and their curriculum will have on students making habits. To provide a high-level perspective of how class influences makerspace involvement, Figure 6 below depicts tool use rates as a function of whether or not students used the makerspace for class purposes or not.

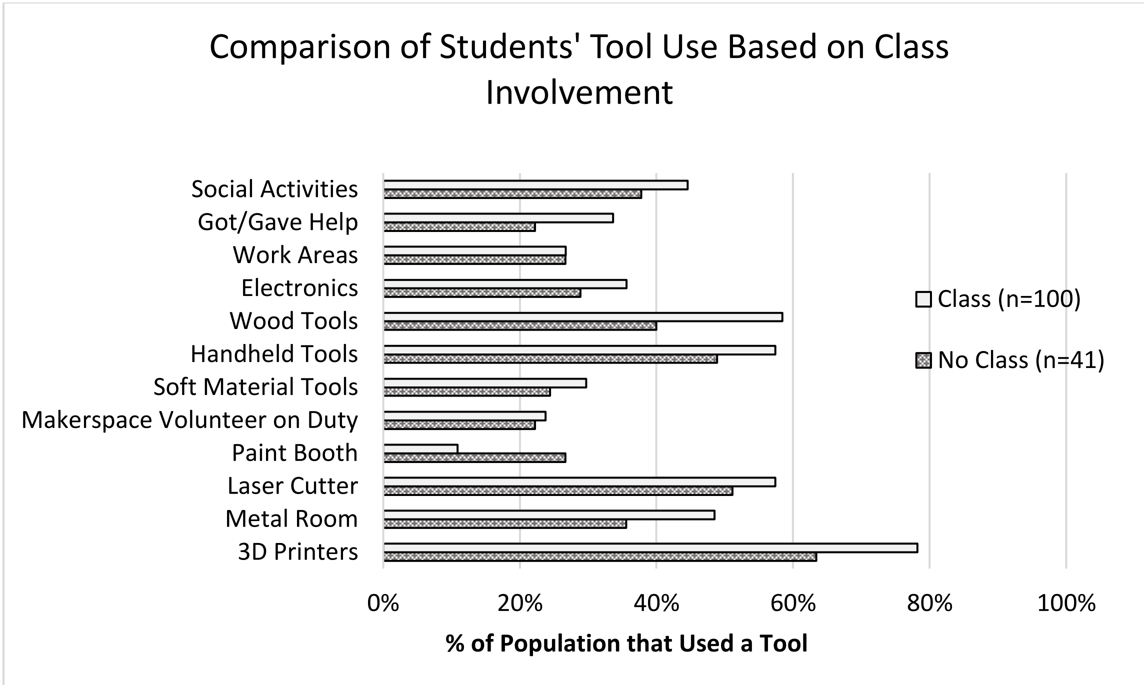

Figure 6— Tool Use as a Function of Class Involvement at School B During the Fall 2020 and Spring 2021 Semesters

Table 9: Chi-Squared Results Comparing Tool Use Between Students Using the Space for Class and Those Who Don't at School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n df χ^2	141 1 3.71	141 1 1.16	141 1 0.04	141 1 7.11	141 1 <0.01*	141 1 0.14
P-Value	0.05*	0.28	0.84	<0.01*	0.96	0.71
Tools	**Handheld Tools**	**Wood Tools**	**Electronics**	**Work Areas**	**Got/Gave Help**	**Social Activities**
n df χ^2	141 1 0.22	141 1 2.67	141 1 0.24	141 1 0.07	141 1 1.25	141 1 0.15
P-Value	0.64	0.10	0.63	0.78	0.26	0.70

There is a general trend of class-based students using tools at a greater rate than those who did not use the space for class (i.e. only for personal or research-based projects). For the most part this trend was insignificant, per Table 9. This general trend of higher tool use amongst students using the space for class is not entirely surprising. Makerspaces are adopted in large part to support the prototyping needs of class, with students often being required to use the space to meet course objectives.

The emphasis placed on prototyping tools at courses at School B has seemed to be influential on how students use the space. Of the 3 prototyping tools commonly promoted in coursework at School B (3D printers, laser cutter, wood tools) as detailed in Table 4 of the Research Sites section, the 3D printers saw significantly more use, while wood tools saw more use with marginal significance per Table 9. The laser cutter and most other tools and activities trended in this direction as well, albeit insignificantly. Far more students sampled used the space for class to some extent, yielding a fairly low sample for 'no class' students that may be impairing this analysis.

The paint booth is the sole tool that saw significantly more use amongst 'no-class' students, likely as this tool is used mostly for aesthetic applications and has relatively little utility for the types of prototypes developed for class.

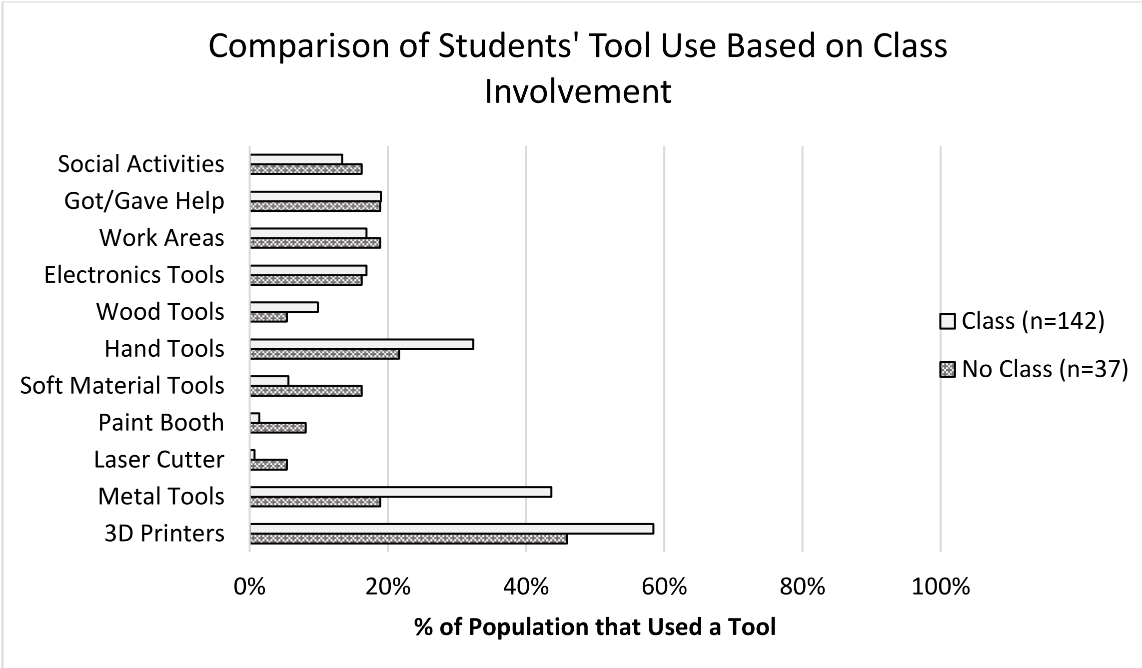

Figure 7 —Tool Use Rates as a Function of Class Involvement at School A During the Fall 2020 and Spring 2021 Semesters

Table 10: Chi-Squared Results Comparing Tool Use Rates Between Students Using the Space for Class and Those Who Don't at School A

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Soft Material Tools	Hand Tools
n	141	141	141	141	141	141
df	1	1	1	1	1	1
χ^2	24.33	23.49	2.10	2.40	1.43	8.63
P-Value	<0.01*	<0.01*	0.15	0.12	0.23	<0.01*
Tools	Wood Tools	Electronics Tools	Work Areas	Got/Gave Help	Social Activities	
n	141	141	141	141	141	
df	1	1	1	1	1	
χ^2	2.41	1.52	0.81	1.57	0.38	
P-Value	0.12	0.22	0.37	0.21	0.54	

The impacts of making related course content at School A can be seen in Figure 6. Unlike School B, class-based students at School A use metal tools at over twice the rate of other students. As detailed in Table 4 there are multiple courses at School A that provide explicit instruction for welding, bending and machining tools that are likely promoting this difference.

At times course-based makerspace requirements seem to have utility beyond promoting the use of the tools those classes require. Per Figure 6, most every tool/activity at School B tends to be used more by class-based students (these differences are not always significant, however). At School A on the other hand, the only tools that improve, are those explicitly taught in class. A breakdown of Figure 5 and Figure 6 detailing how the type of class influences tool use rates may help cast a light on this discrepancy.

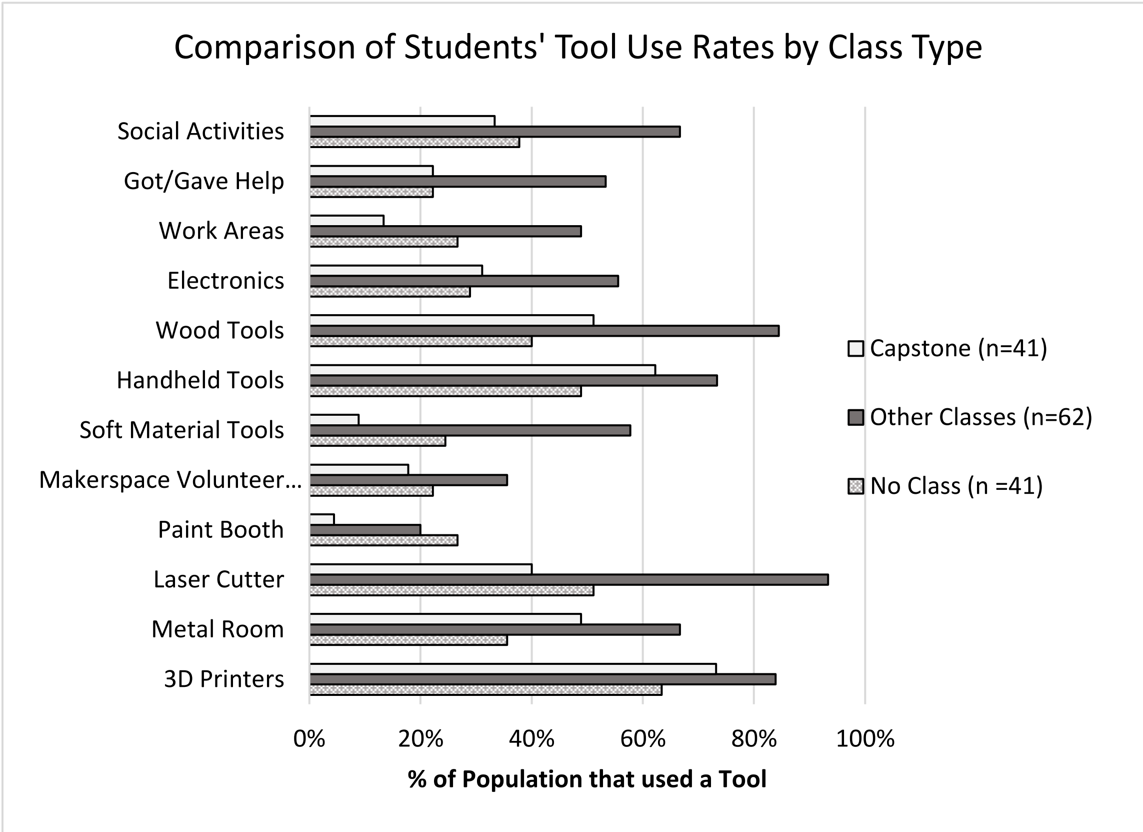

Figure 8 — Tool Use Rates by Class Type at School B During the Fall 2020 and Spring 2021 Semesters

It is immediately evident at School B that this trend of greater class-based tool use first seen in Figure 6 is almost wholly driven by 'other classes' which for School B consists of the 'Computer Aided Engineering' and 'ME sophomore design' courses. To reiterate, both of these are required courses that mandate heavy makerspace involvement per Table 4. These more introductory courses not only teach a wide variety of tools, but may allow for a broader scope with respect to the type of design problems assigned compared to capstone. Whereas capstone students may only use a handful of tools to develop a solution to the one niche problem they focus on, students in introductory courses may explore an extensive array of tools as they tackle the various design problems assigned in class. This in turn perhaps explains why the diversity of tools and use rates for students in the 'other class' group are as high as they are compared to capstone and 'no-class' students.

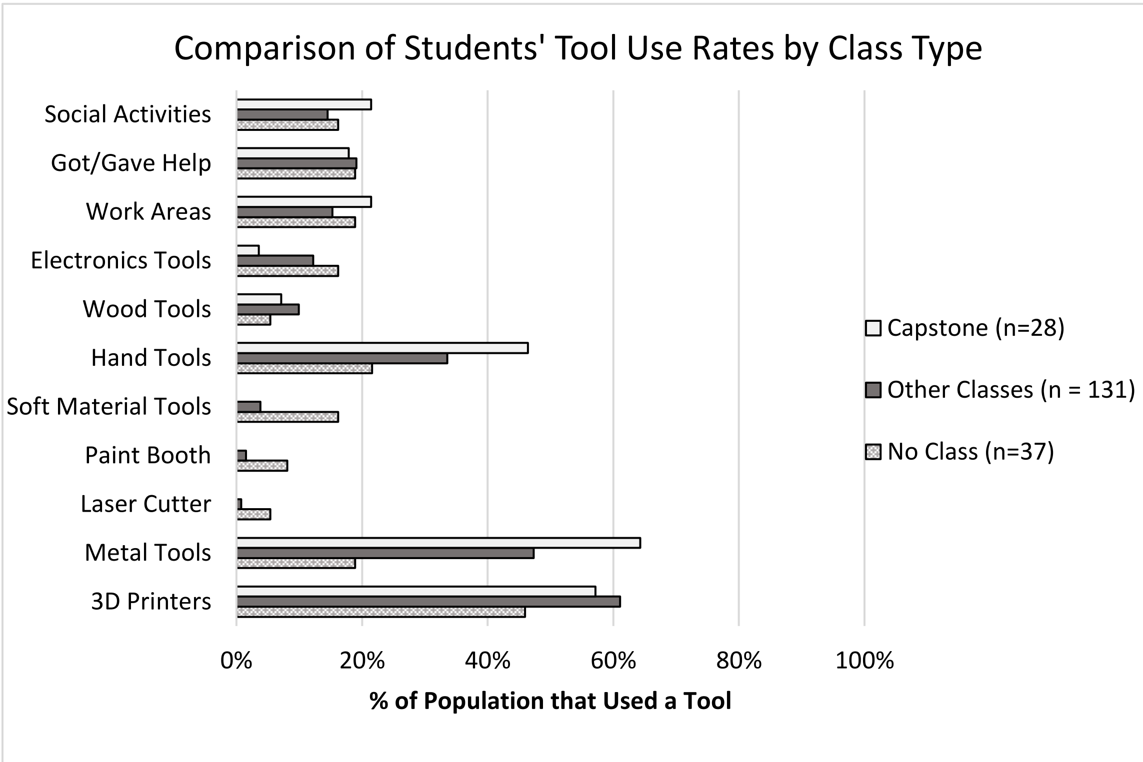

Figure 9 — Tool Use Rates by Class Type at School A During the Fall 2020 and Spring 2021 Semesters

Likely due to tool training curriculum of courses at School A, 'other classes' simply do not have the same driving force that they do at School B, demonstrating significantly lower tool use rates per Figure 9. School A does have 3 non-capstone courses as outlined in Table 4 that provide explicit training for 3D printers, hand tools, and several metal tools. Furthermore, much of the training from 'other classes' at School A is not geared towards conventional making. Metal tools training from the 'Materials/Manufacturing' course at School A for instance are designed to prepare students for the course's lab assignments and not the typical design problems or prototyping that makerspaces are typically used for. Accordingly, at School A some students may use metal tools in the makerspace to meet course objectives, and not engage with any other tools in the space. That being said, Capstone students use metal tools at School A at a very high rate as well. While capstone students at both schools have agency over what projects they pursue and what tools they use, there may be factors at School A or School A's capstone curriculum that are not immediately apparent, but drive capstone students to use metal tools more often than they do at School B.

Accordingly, it would seem that how class required tool training can be an effective tool depending on how it is implemented. When such training is paired with a series of open-ended design problems it may be the case that students explore the manufacturing and prototyping solution space to a greater extent, as well as use a more diverse set of tools. Even going so far as to learn tools not explicitly taught or often associated with the classes they are enrolled in. When these course-based requirements are for the sole purpose of meeting more rigid class requirements like labs however it could be the case that students are not engaging with the space as much as they reasonably could.

1.11 Makerspace Use amongst Underrepresented Minorities

There is substantial research on the topic of URM experiences in engineering education as well as in makerspaces specifically, indicating that many URM students face barriers that strip of them of a sense of community and belonging in university makerspaces [21, 45, 69-71].

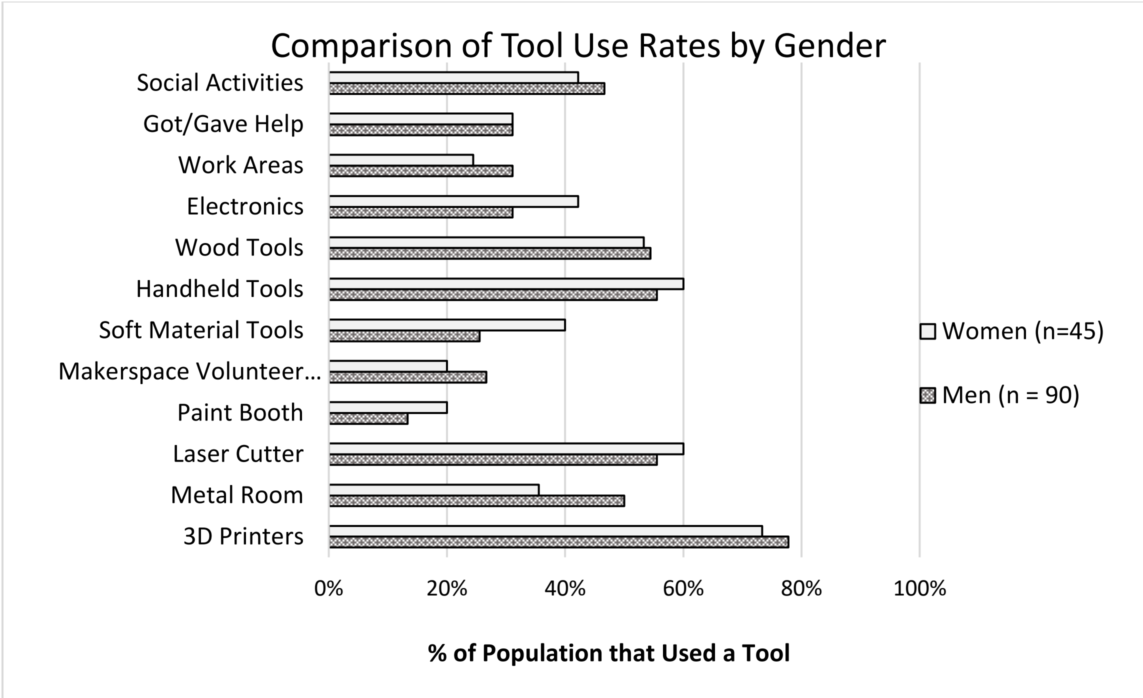

Figure 10 —Tool Use Rates as a Function of Gender at School B During the Fall 2020 and Spring 2021 Semesters

Table 11: Chi-Squared Results Comparing Tool Use Rates Between Women and Men at School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n	135	135	135	135	135	135
df	1	1	1	1	1	1
χ^2	0.33	2.53	0.24	1.02	0.72	2.96
P-Value	0.57	0.11	0.62	0.31	0.40	0.09
Tools	Handheld Tools	Wood Tools	Electronics	Work Areas	Got/Gave Help	Social Activities
n	135	135	135	135	135	135
df	1	1	1	1	1	1
χ^2	0.24	0.01	1.63	0.65	<0.01	0.24
P-Value	0.62	0.90	0.20	0.42	1.00	0.62

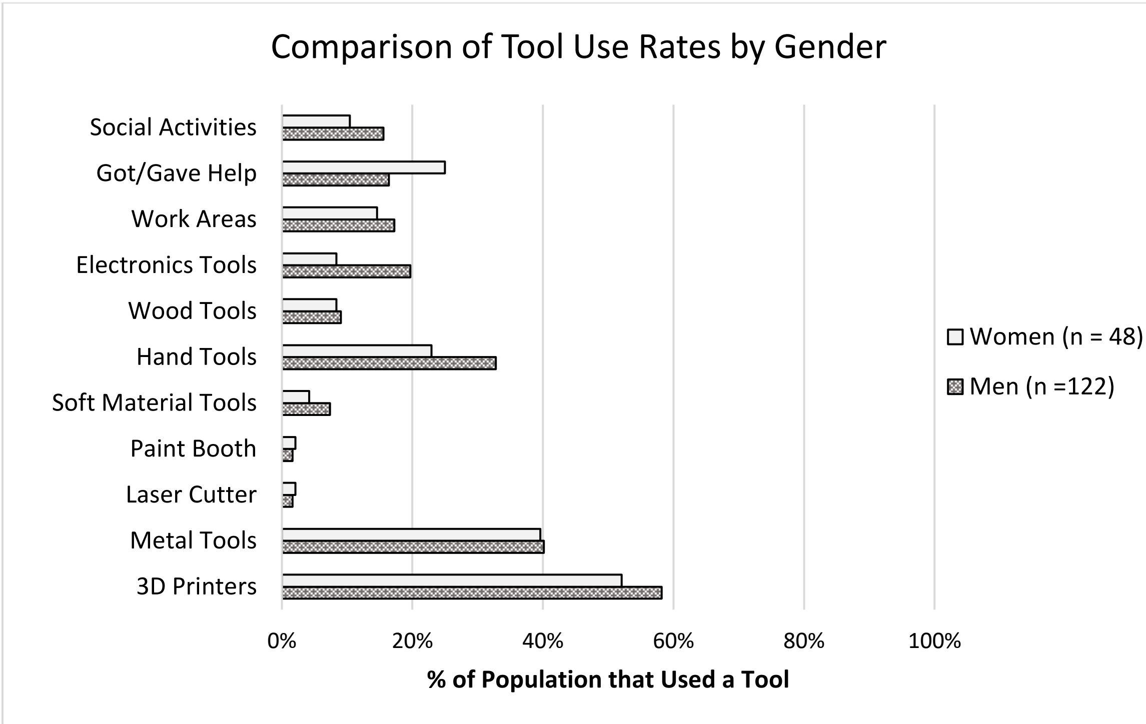

Figure 11 —Tool Use Rates as a Function of Gender at School A During the Fall 2020 and Spring 2021 Semesters

Table 12: Chi-Squared Results Comparing Tool Use Rates Between Women and Men at School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n	135	135	135	135	135	135
df	1	1	1	1	1	1
χ^2	0.33	2.53	0.24	1.02	0.72	2.96
P-Value	0.57	0.11	0.62	0.31	0.40	0.09
Tools	**Handheld Tools**	**Wood Tools**	**Electronics**	**Work Areas**	**Got/Gave Help**	**Social Activities**
n	135	135	135	135	135	135
df	1	1	1	1	1	1
χ^2	0.24	0.01	1.63	0.65	<0.01	0.24
P-Value	0.62	0.90	0.20	0.42	1.00	0.62

Interestingly, as shown in Figure 10 and Figure 11 women at schools A and B are engaging with the makerspace at comparable rates to men for all tools and activities. Table 11 and Table 12 corroborate this, with no significant differences in tool use rates between men and women at either school. Furthermore, there are no insignificant trending differences between these groups either.

Considering the barriers women face in STEM and as makers it is in part surprising that women are engaging with tools and activities in the space at similar rates to men, as one might intuitively expect that these barriers may prevent women exploring and using the space as extensively as men. There is considerable work that has found women participate in makerspaces less than men, but have defined this participation as the proportion of women that use the space or the time spent by participants of each gender, and have not used the metric of tool use rates as done in this work [35, 72, 73]. Given that this work reports women engaging with tools/activities in the space no less than men, it may be the case that the greatest barriers to women in makerspaces are at the entrance, with women avoiding the space due to heightened design anxiety, or lack of sense of belonging, whether specific to makerspaces or a lack of sense of belonging for engineering in general [21, 74]. Once this initial hurdle is overcome, it may be that women find communities within makerspaces and in turn that the challenges women face become more manageable, ultimately resulting in women engaging with the space at the same rate as anyone else.

Beyond the use rates of those already in the makerspace it is important to consider how the proportions of men and women in the space compare to the same gender proportions for the engineering programs these makerspaces support. Per the sample sizes denoted in Figure 10, women make up 33.3% of all participants. At School B however women only constitute 21.8% and 12.9% of all mechanical and aerospace engineering majors respectively [75, 76], which are the two most popular majors amongst women surveyed in this study, pointing towards a considerable overrepresentation of women at School B's makerspace. A similar effect is seen at School A, where the ME and AE program is 20.5%, and 8.3% women respectively [77-79], while 27% of survey participants from School A are women.

While these proportions may in part be due to the efforts of students, clubs, and faculty to promote an inclusive atmosphere in these makerspaces, it is possible these ratios areinflated due to the survey methodology used. Regardless of the survey subject matter, women have been shown to typically respond to surveys at rates higher than those of men, especially amongst college aged students [62, 80, 81]. In addition, surveys often attract the most and least satisfied members of a population [55]. Accordingly, these disproportionately high sample sizes of women may indicate that women are completing this survey more often than others in effort to spur change in a makerspace that is not providing an equitable experience for them.

There are certainly many other factors that could drive this overrepresentation, so to determine whether there is a sampling bias ofun/satisfied women responding, in future survey efforts it will be pertinent to elicit students' perceptions of the space to determine whether the makerspace is as equitable with respect to gender as it would seem, or whether women's response rates and tool use rates are driven by inequities they suffer while in these spaces.

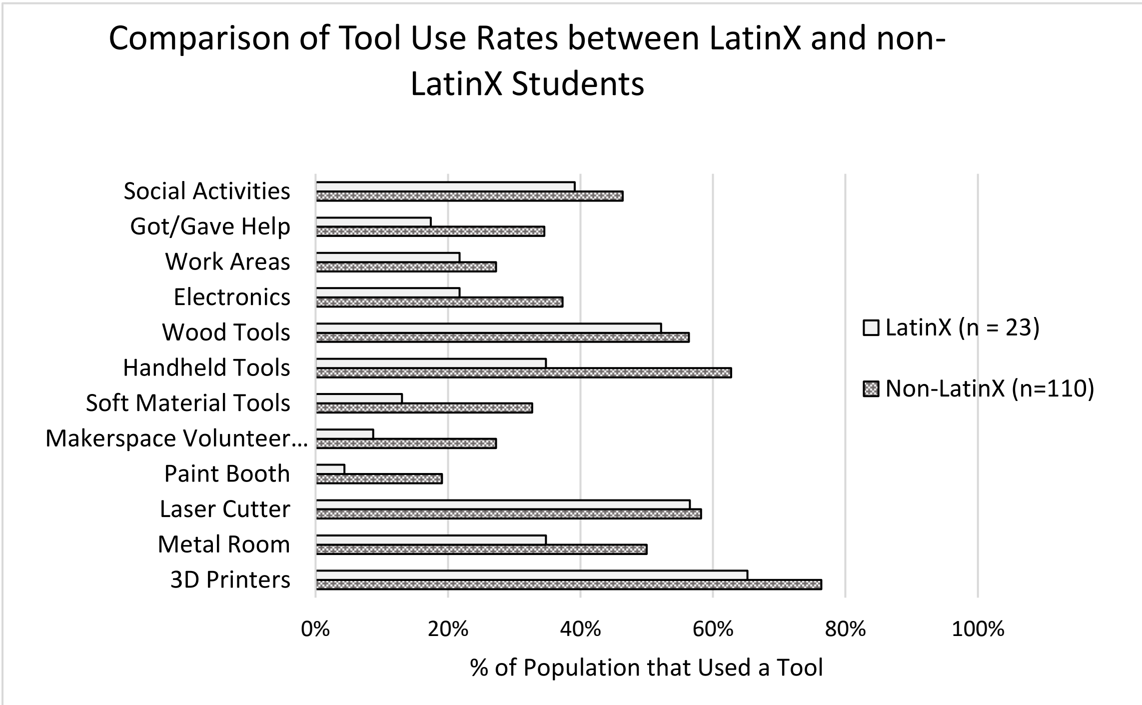

Figure 12 — Tool Use Rates as a Function of LatinX Status at School B

Table 13: Chi-Squared Results Comparing Tool Use Rates Between LatinX and non- LatinX students at School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n	133	133	133	133	133	133
df	1	1	1	1	1	1
χ^2	1.24	1.77	0.02	3.00	3.59	3.56
P-Value	0.27	0.18	0.88	0.08	0.06	0.06
Tools	Handheld Tools	Wood Tools	Electronics	Work Areas	Got/Gave Help	Social Activities
n	133	133	133	133	133	133
df	1	1	1	1	1	1
χ^2	6.09	0.14	2.03	0.30	2.59	0.40
P-Value	0.01*	0.71	0.15	0.58	0.11	0.53

While outcomes may be seemingly equitable with respect to gender for School B, this is not the case for LatinX students, with non- LatinX students having generally higher tool use rates, with intermittent, mostly marginal, significance. Previous literature has emphasized how a sense of belonging is important for successful making/makerspace outcomes [82, 83]. Furthermore, having minority authority figures in the space has been shown to help promote more engagement and greater participation among said minority groups [69]. Students entering likely see the student workers at School A and the makerspace volunteers at School B as authority figures. Many of these collaborative activities that help develop these sub-communities and foster a sense of belonging amongst students are particularly low amongst LatinX students. LatinX students are makerspace volunteers significantly less often than other students, and with marginal significance are less likely to give/receive help as well as seen in Figure 12. One hypothesis backed by the prior literature is that at School B LatinX makers are engaging with the space less due to a lack of sense of belonging, that ultimately stems from the absence of LatinX makerspace volunteers in this space.

Similar to women's results, LatinX students are again overrepresented in this data, perhaps due to frustrations LatinX students may have with this space. 4.1% of the engineering department at School B is LatinX [84] compared to 17% of participants on this survey identifying as LatinX. Especially considering that tool use rates at School B are lower for LatinX students, it would likely be overly-optimistic to assume that this 17% figure is an accurate indication of the proportion of LatinX students in this makerspace. Especially considering Hispanic participants often respond to surveys less frequently than white participants [81]

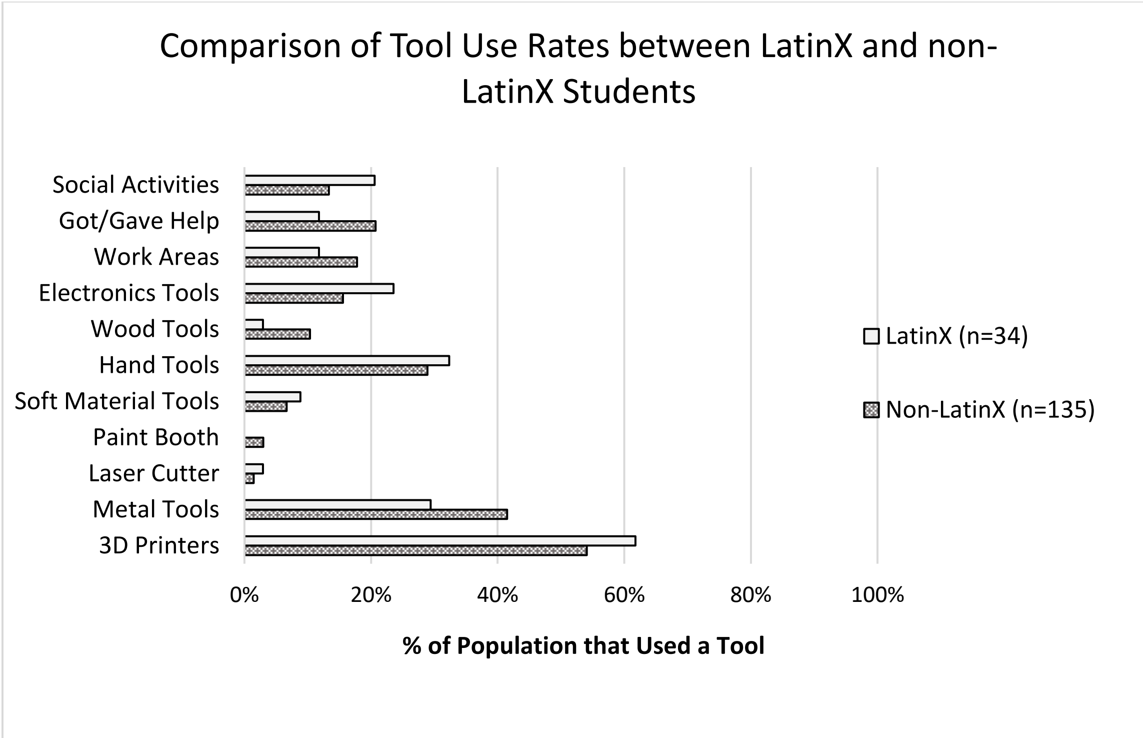

Figure 13 — Tool Use Rates as a Function of LatinX Status at School A

Table 14: Chi-Squared Results Comparing Tool Use Rates Between LatinX and non- LatinX students at School A

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Soft Material Tools	Hand Tools
n	169	169	169	169	169	169
df	1	1	1	1	1	1
χ^2	0.65	1.66	0.33	1.03	0.19	0.16
P-Value	0.42	0.20	0.56	0.31	0.66	0.69
Tools	Wood Tools	Electronics Tools	Work Areas	Got/Gave Help	Social Activities	
n	169	169	169	169	169	
df	1	1	1	1	1	
χ^2	1.85	1.21	0.71	1.43	1.13	
P-Value	0.17	0.27	0.40	0.23	0.29	

School A has little to no disparities with respect to LatinX status. This in part may be due to School A being a Hispanic-serving School with a significantly larger LatinX community. LatinX students at School A represent 21.83% of students in the engineering program [78], and 20% of all survey respondents. While the proportion of survey respondents who are LatinX at both schools is similar, the actual proportions in the School and engineering program are not, with School A having nearly 4 times the LatinX students. Reaching a certain critical mass of URM students has demonstrated to shift dynamics in a way that improves performance amongst minorities in both academic and professional settings [85, 86]. While a LatinX makerspace population of 20% is certainly a number that we should strive to improve, this relatively large population may constitute a critical mass. Having a critical mass of LatinX students may make for not only more LatinX students in the makerspaces, but students with more confidence to explore the space and engage with more tools, as seen at School A. Conversely, the absence of a large LatinX community at School B may result in a makerspace dynamic where LatinX students do not have this same confidence, and in turn do not use the space as extensively.

Again considering the many barriers that face URM students in makerspaces, it is in part surprising that there are not more significant differences between LatinX and non-LatinX students in terms of tool use rates. LatinX student samples at both schools for this research effort are low (n=23, n=34) respectively, so increasing these samples in future work may very well provide more concrete insights into LatinX students experiences within these makerspaces.

In addition to improving the statistical power of this LatinX vs. Non-LatinX analysis, sampling more students would also enable other similar analysis. Many URM groups like Black or Native American students could not be reported due to extremely small sample sizes reinforcing the need to over-sample in future work and for other research methods to be used that capture the experiences of these groups.

1.12 Makerspaces as a Commons

While makerspaces serve predominantly as a space for familiarizing students with manufacturing and developing their design confidence, for many they also have utility as a social area. Students often use these spaces to study, socialize with their friends, bounce design ideas off one another and so on. Due to Covid restrictions, one would expect that the degree of social engagement in the space is lower than it normally is as students socially distance or avoid occupied spaces. Per Figure 4 however it is clear that students have been engaging in social activities during Covid at the same rates they were before the pandemic.

When comparing students who use the space for social activities to those who do not, it is immediately apparent that students using the space in this social capacity are drastically outpacing their peers.

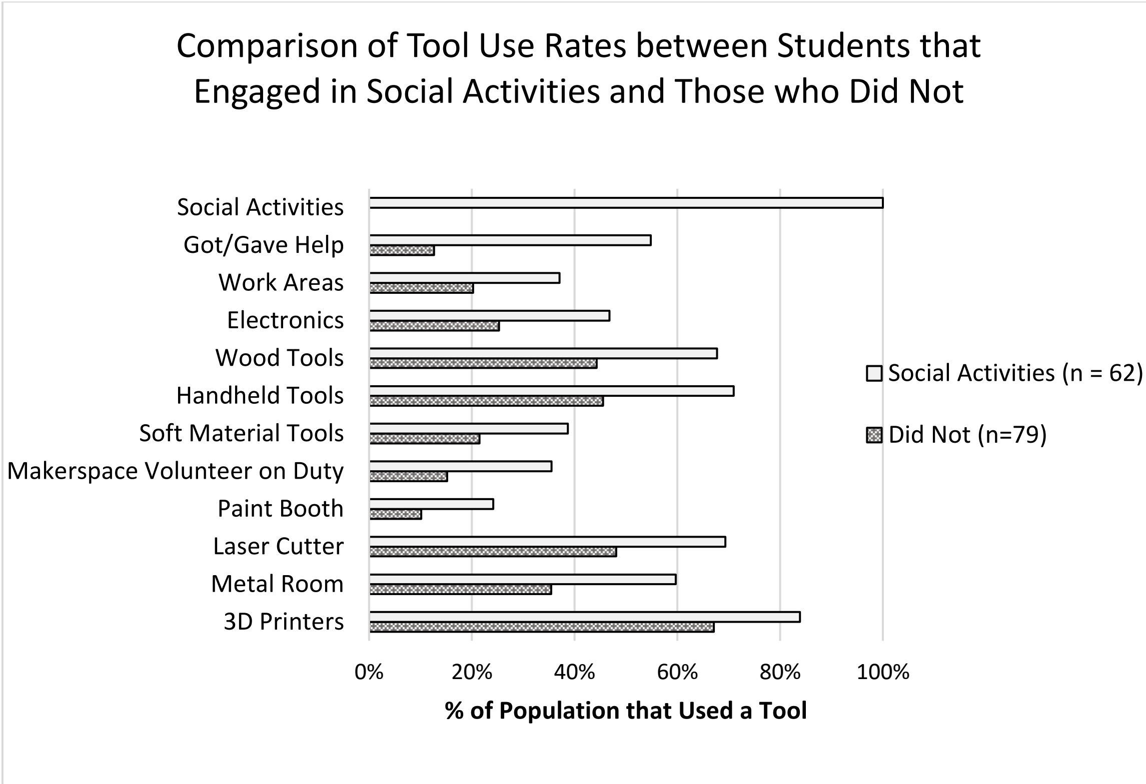

Figure 14 — Tool Use Rates as a function of Social Engagement at School B

Table 15: Chi-Squared Results Comparing Tool Use Rates Between Students that Socialized and those who didn't, School B

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Makerspace Volunteer on Duty	Soft Material Tools
n	141	141	141	141	141	141
df	1	1	1	1	1	1
χ^2	5.15	8.21	6.42	5.04	7.82	4.98
P-Value	0.02*	<0.01*	0.01*	0.02*	<0.01*	0.03*
Tools	**Handheld Tools**	**Wood Tools**	**Electronics**	**Work Areas**	**Got/Gave Help**	**Social Activities**
n	141	141	141	141	141	141
df	1	1	1	1	1	1
χ^2	9.13	7.70	7.05	4.93	28.79	141.00
P-Value	<0.01*	<0.01*	<0.01*	0.03*	<0.01*	<0.01*

Table 15 validates this, finding that social students used all tools and engaged in all activities at a significantly greater rate than those who did not socialize. It is tempting to claim that student socialization is the driving force behind this greater involvement, but there could certainly be other factors at work that bring the causal direction into focus. More specifically, whether socialization leads to greater tool use or greater tool use leads to more socialization is ambiguous.

It may be the case that students who use the space for social activities spend more time in the makerspace end up watching others more, build confidence, and ultimately use a greater diversity of tools more frequently than they otherwise would. Conversely, students who are heavily involved in the space and use many tools for any number of other unrelated reasons, may be more comfortable using the space for social activities because of how often they use this space. Both of these could be true as well, creating a positive feedback loop between socialization and making.

Regardless of this causal direction, there is a strong relationship between socialization and makerspace engagement and as a result should be promoted or at a minimum a makerspace should have the means to facilitate such activity. Features like white boards, desks, charging for laptops, comfortable seating, areas for socializing, and other non-making infrastructure are all conducive to social engagement within the makerspace and should be included to ensure students who may be inclined to use the space for these valuable non-making activities have the ability to do so.

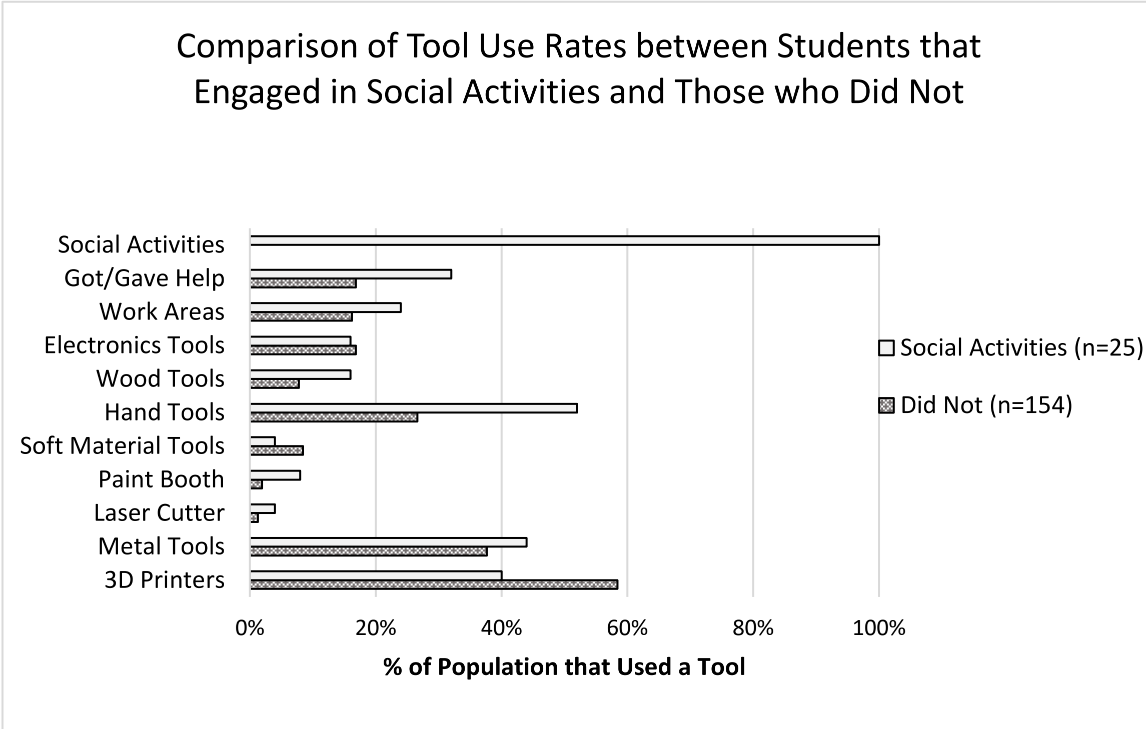

Figure 15 — Tool Use Rates as a function of Social Engagement at School A

Table 16: Chi-Squared Results Comparing Tool Use Rates Between Students that Socialized and those who didn't, School A

Tools	3D Printers	Metal Room	Laser Cutter	Paint Booth	Soft Material Tools	Hand Tools
n	179	179	179	179	179	179
df	1	1	1	1	1	1
χ^2	2.97	0.36	0.95	2.90	0.59	6.57
P-Value	0.08	0.55	0.33	0.09	0.44	0.01*
Tools	Wood Tools	Electronics Tools	Work Areas	Got/Gave Help	Social Activities	
	179	179	179	179	179	
	1	1	1	1	1	
	1.78	0.01	0.91	3.19	179.00	
P-Value	0.18	0.91	0.34	0.07	<0.01*	

At Institution A there is still a trend of higher use for students using the space as a commons, this difference however is inconsistent and generally less pronounced per Figure 15 and Table 16. This in large part is likely due to discrepancies in Covid policies between schools. As discussed in the Research Sites section, School A has imposed more stringent regulations, asking students not to use the space for non-making activities, especially socialization, whereas School B only imposed capacity limits. The fact that socialization still played a significant and positive role for many tools like 3D printers and hand tools at School A despite these restrictions is an impressive testament to the important role socialization and collaboration play in a makerspace. In a similar vein, the differences between a makerspace with socialization and without are certainly stark as well, although without data collected after Covid restrictions are lifted at both spaces, it will be difficult to assert that Covid policy is the main source of variance between these two schools, and not other factors.

It may also be the case that having a staff comprised of student volunteers is responsible for the heightened social engagement at School B. Having a space managed by students may make for an environment where students feel more empowered to change things, a more welcoming environment, one where other students are comfortable reaching out for help, and one where using the space for non-making activities is welcomed. To parse out the influence of Covid as well as management structure it will be pertinent to collect similar data in future semesters when Covid restrictions are not in effect and at many other schools. In doing so, it will be possible to ascertain whether this lower social engagement at School A is a transient effect of Covid regulations or a permanent consequence of other differences between spaces.

CONCLUSION

The makerspaces covered in this work would appear more similar than not, containing similar tooling and making-related courses, as well as serving students that are motivated to use the space for similar reasons. Despite these similarities, there are notable observed differences in how students use these spaces. Which factors drive these differences is not entirely certain, but this work points towards several factors that may be in part responsible.

The order students learn tools in is one characteristic of student makerspace use that varies between these institutions. Differences in class-based tool training requirements may have influence over this factor, with School B emphasizing laser cutters and seeing a greater proportion of students learn this tool. In addition, such data may have utility for highlighting how students' progress as they become more involved in the makerspace. At both schools, the rate at which students learn wood tools grows from their 1^{st} to 5^{th} tool learned. Whether this is evidence of students becoming more comfortable with the space, and experimenting with more challenging tools or other factors cannot be concretely claimed from this work. Especially considering this data was collected during Covid, whether this finding is transient or genuine characteristic of students making journeys is ambiguous. That these trends are observable however highlights how this style of analysis may be valuable for providing quantitative insights into student learning habits in future work.

The Covid pandemic and the restrictions placed on makerspaces to impede the spread of this disease have had an adverse impact on students' engagement with the space. With the exception of social activities and more niche tools, tool use rates were recorded as being significantly lower during Covid than they were prior at School B. That social activities did not decline is interesting considering the number of alternative physical and virtual spaces students can use for social activities and the emphasis placed on social distancing and similar restrictions. It may be the case that engagement in these social activities are as resilient as they are in the face of Covid restrictions because students highly value them, which is consistent with prior literature [50, 87].

Courses and the makerspace can be impactful on student making outcomes as well. Requiring students to engage in making activities through class has been shown to lead to more long-term makerspace engagement amongst less motivated engineering students [15]. Furthermore, students' design anxiety has been shown to be rapidly ameliorated by making related coursework [37]. This may be because requiring students to use the makerspace and use certain tools provides an explicit reason that a student belongs in the space, and may also prompt students to use tools they may not be familiar with and may otherwise be easily deterred from using. How making is integrated into coursework likely has considerable influence over how effective course making requirements promote general makerspace engagement. School A has a similar number of making related class as School B, but per Figure 7, coursework may not be a particularly high impact factor for all tools. It may be that when course requirements introduce students to the space early in their college career, require more explicit training, and guide students through a diverse array of tools it may promote greater engagement not only with the tools taught, but throughout the space in general. There is some prior work that supports this notion, finding that students required to 3D Print their own parts are 81% more likely to become involved in a makerspace than those who participated on a team that printed a part [15], highlighting how some course requirements are more effective than others. Accordingly, it may be the case that when course requirements are limited, do not mandate training, and are mostly found for terminal classes like capstone, makerspace engagement may not be enhanced by class as effectively as possible.

URM face a variety of challenges in STEM education and makerspaces in particular, that often lead to URM using makerspaces less than others [35, 73]. From the analysis of women and LatinX students using these two makerspaces however, we observe women participating at similar rates to men at School B and LatinX students with similar rates as non-LatinX at School A. One possible reason for this observation could be that a critical mass exists [85, 86, 88]. School B tends to have a critical mass of women on their student leadership board and future work needs to explore if they also have it with their student volunteers. At School A, which is a Hispanic-serving school, tool use rates between LatinX and non-LatinX students are comparable, whereas at School B where LatinX students represent only 4.1% of all engineering students[84], tool rates for this group suffer drastically. Whether this discrepancy is due to the presence of a larger school-wide LatinX community is not certain, as there could potentially be other barriers for LatinX students at School B that are not present at School A. The same could be true for women and future work is needed.

At both schools, URM students are overrepresented as survey participants which may in part be due to non-response biases. More specifically, that URM students may be responding at elevated rates in effort to voice their concerns/perspective and motivate change in the makerspace. This elevated response rates amongst URM students is not wholly consistent with prior literature. Previous survey research has found that women often respond more frequently to surveys, while people of color respond more rarely [62, 80, 81]. While women respond more than men in this work, that Hispanic/LatinX students do as well is in part surprising, considering in previous work this has not been the case.

This data points to socialization as a likely powerful method for motivating engagement in makerspaces. The current results only demonstrate correlation between greater tool use and social activities, but the results are promising. The utility in these non-making activities is evident at both schools, where students who use this space for social activities end up using the drastically more tools. Socializing may be making students more comfortable with the space by spending more time in the space, as well as spending more time collaborating with peers. Conversely, students who are highly motivated and already use the space often may be more inclined to use it as a space to study, hang out or engage in any other social activities. It is certainly possible that both of these explanations are true.

Coursework, socialization within the space and demographics are all factors with the potential to sway how students' interface with their space. Ultimately, these factors are all contributing to changing a broader making culture. This culture is undoubtedly influenced by a smorgasbord of other factors such as the physical layout of the space, its look and feel, where on campus the space is situated, and more. Accordingly, it is difficult to parse out the specific impacts of each of these factors, as these other elements are likely contributing to the results presented. The findings of this work however do provide interesting insights into how makerspaces are being used, and what factors may be particularly highly impactful for students. It provides guidance where there previously was not available empirical data and significant motivation for future work.

LIMITATIONS

1.13 Response Rates

For the 3 semesters data was collected from Fall 2019, Fall 2020 and Spring 2021 response rates from capstone classes were 67%, 6% and 8% respectively. While a large spread, all of these response rates are individually within a reasonable range for student surveys using the survey methodologies employed in this work [89]. Recruitment was performed fairly differently for Fall 2019 period compared to subsequent data collections that likely contributed to this difference. Fall 2019 involved physical in-person announcements at the beginning of class sessions. Students could also complete it during the end of semester expo and payments were handed out during the senior design expo in Fall 2019. During Covid however, classes were virtual and these announcements were also made virtually. Without someone physically in front of you, it is certainly easier to zone out entirely, likely hurting these response rates. Furthermore, capstone is already a challenging course, and when compounded by Covid it may have created a particularly stressful and hectic atmosphere. In turn, students have certainly had less bandwidth than in previous semesters, potentially resulting in less patience or time to volunteer for a survey such as this. Additionally, students were paid $40 for this initial pilot survey because it was added to another study which had a longer survey as opposed to $20 for the versions in Fall 20 and Spring 21.

1.14 Survey and Other Methodology Changes

Throughout the course of this work notable changes were made to the surveys, potentially limiting comparisons between data from different semesters as well as between schools. These survey changes were made to correct errors in previous surveys, to expand the scope of data collection as well as to promote inclusivity. As surveys developed it became clear that there were tools students used in makerspaces that had not been listed as answers, as well as some tools listed that were no longer available in the space. When identified these errors were corrected. Students always had the option to report using a tool not listed, but for unlisted tools it may be possible students forgot they had used it, and not having the option as a survey answer in earlier surveys may have resulted in a loss of data. In addition, students may have remembered they had used an unlisted tool but did not want to spend the time manually entering in these tools, and 'clicked through' this question. Most of these differences were minor, with the exception of hand tools. Initially, hand tools were listed as one generic answer, but was later expanded to include all hand tools within the space.

There were considerable differences between the Fall 19 survey, which was only implemented at School B and subsequent surveys. Notably, for tool use students were only asked which general categories of tools they used instead of specific tools. This may have caused a loss of data, as listing specific tools has the potential to jog students' memory so they list tools they may have otherwise forgot.

Recruiting for Fall 19 also involved 40$ worth of compensation as opposed to 20$, likely increasing recruitment rates for this round of data collection.

An oversight was made in generating surveys during the Spring 21 data collection for School A. For the question regarding the order students' learned tools in, hand tools were not listed as an option and unfortunately this datapoint was lost altogether. As a result, Figures 2 and 3 only depicts data regarding the order of tools learned for the Fall 20 data collection, so that data for both schools may be compared.

Verbiage regarding Hispanic/LatinX students was changed from "Hispanic" found in Fall 19 surveys to "LatinX" in later surveys as a more inclusive option. While impact from this may be minor, there may be some students who identify as Hispanic and not LatinX and vice versa due to not being familiar with the term. As a result, this may have invoked some error into questions pertaining to Hispanic/LatinX status as well as race.

1.15 Covid and Data Validity

Most observations herein as well as any comparisons drawn between schools are obscured by the Covid pandemic. While trends in makerspace use may be a function of class involvement, school culture, makerspace design, or other factors identified in this work as potentially impactful, whether these trends are indicative of typical makerspace use or are specific to makerspace use during Covid is unknown. Even beyond the regulations placed on makerspaces, changes to course structure, level of general stress amongst students, changes to typical daily routines and other factors may have influence that is not possible to comprehensively capture.

These influences may be controlled for to some extent, considering pilot data was collected prior to Covid, allowing for some degree of insight into how Covid has altered use of these spaces. Due to drastic changes in survey design and recruiting between the Fall 19 and subsequent data collections however, it is difficult to claim this comparison is a perfectly valid one-to-one comparison. This holds especially true for any claims regarding differences between institutions, as this pre-Covid pilot data was only collected at School B. As a result, any claims made about the impacts of Covid at School A rely on the assumption that changes in makerspace use due to Covid are similar between institutions. While these schools and their makerspaces are more similar than they are different in most regards, that does not necessarily mean that their respective changes in makerspace use are identical. Establishing a baseline for what non-Covid makerspace use looks like at School A will help remove this ambiguity and enable a better understanding of which differences between schools are due to Covid, and which are due to other factors more central to this work (makerspace design, school culture, etc.).

FUTURE WORK

To further provide insight into how these factors impact students, future survey data collection should elicit information regarding student perceptions of makerspaces. A major focus of this work has been in investigating how students including URM students interact with the space in terms of tool use rates. URM demonstrated lower tool use rates than their peers at one School but not at the HSI University Past literature has identified a lack of a sense of belonging as a major barrier for URM students in makerspaces [22, 73], whether this barrier is responsible for the lower tool use rates seen cannot be determined from this work. It may be the case that certain schools have fostered more welcoming makerspace cultures than others. In turn, this could explain why URM students such as LatinX students at School A engage with the space less, while LatinX students at School B engage at similar rates to any other student. Data about students attitudes and perceptions of the makerspace will be needed to test this hypothesis. A correlation with this data and tool use rates could help uncover whether lower tool use rates are directly related to a lack of sense of belonging. Furthermore, they could highlight to what extent URM students feel welcome in these spaces, ultimately improving our understanding of the challenges facing marginalized groups in STEM and makerspaces specifically.

Increasing sample size moving forward will be critical to improve statistical power in general as well as make use of the survey's full functionality. Many questions included in the survey seen in APPENDIX A. Anonymized Survey Examples, are not reported due to low samples. Data regarding race, for instance, was collected but the only groups with samples large enough report were white and Asian (which demonstrated no differences), as well as LatinX. In a similar vein, non-binary students tool use results cannot be spoken to due to similarly low sample sizes. All statistical analysis already performed in this work would also be enhanced by larger samples, as many of these samples are just large enough to be considered large enough (n>30) for conventional hypothesis testing.

Increased sampling would not only allow for more thorough analysis of how race and/or gender influence how students interact with makerspaces, but could also allow for investigation into how demographic factors interact with other academic or experiential factors. This data also did not have large enough samples to evaluate intersectionality, such as race and gender (e.g., black women). Past literature has identified that women are often times deterred from engaging in making activities in capstone classes, and instead forced into more administrative roles [74]. Accordingly, comparing tool use rates of women in capstone to men in capstone could provide a novel insight into this phenomenon that could in turn improve equity in these courses. While there are a sufficient number of women in the current data for conventional analysis, there are only 12 women in capstone represented in this work, preventing analysis of how these two factors may interact. Casting a wider net or oversampling in future survey distributions could enable these types of multi-factor analysis, providing a more detailed understanding of how demographics and academics intersect.

In addition to better understanding how various factors interact and create unique challenges and experiences for URM students, there are many other factors the tool use data cannot be analyzed by due to limited samples. More specifically, the resolution of analysis regarding course involvement, student motivations for using the space, as well as major may all be improved through increased sample sizes. Currently, sample size has restricted analysis of course influence on tool use to a comparison between students who use the space for class, and those who did not. By increasing sample sizes, the impacts of specific courses could be spoken to, allowing for a more concrete claims to be made about the role these different classes play in the makerspace. Similarly, there are several key motivations that drive students to use makerspaces, and course related motivations are currently the only one that may be analyzed. Personal, research, club, and entrepreneurial making are all known use cases of makerspaces, and by capturing a greater number of students who use the space for these other non-class motivations, future work may better characterize how these extracurricular motivations affect students use of the space.

The scope of data collection should also be expanded to include additional makerspaces at schools A and B, as well as other schools. Ultimately, with only two schools to compare it is difficult to make concrete claims about how the design, management and culture of a given makerspace influence its use. It is also difficult to attribute differences in tool use rates to any other factors, as there may be some unique characteristic of a makerspace that is driving the observed change. Collecting data from multiple universities may help identify whether the influence of a given factor is part of a broader consistent trend, or an isolated incident likely unrelated to the observed change in tool use.

Lastly, data collection should continue after Covid restrictions are lifted to investigate what impact changes in course requirements, makerspace policy, and general anxiety amongst students have had on makerspace use. While some pilot data was collected highlighting potential differences in makerspace use before and during Covid, the scope of surveys has increased substantially to collect more extensive academic and demographic information, as well as more detailed tool use data. While collecting data during Covid has certainly adversely impacted survey response rates, and the engagement of students in makerspaces, it presents a unique opportunity to study how resilient students' involvement with certain tools and activities is when faced with a major barrier like Covid and the corresponding restrictions on makerspaces. Tools that students are easily deterred from using, as well as tools students cannot live without may be identified by comparing tool use data during a pandemic to tool use data under normal circumstances. In turn, educators may better understand what threats and opportunities exist in their makerspaces, ultimately designing and managing spaces so that they more effectively meet the needs of students.

APPENDIX A. ANONYMIZED SURVEY EXAMPLES

A.1 Entry/Exit Survey Example with All Survey Logic Annotated

Start of Block: Maker Survey

*

◯ Email: (3) ____

◯ [Redacted] name (e.g., [Redacted]) (5)

____

Q75 Are you completing the Entry or Exit survey?

- ○ Enter (1)
- ○ Exit (2)

Q101 Payment is only possible with the completed consent form. The consent form can be found here: [URL Redacted]

Page Break

End of Block: Maker Survey

Start of Block: Enter

Page Break

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

Q81 For what purposes did you come to the [Makerspace] today? Please list projects you plan to work on, tools you plan to use, etc.

____

____

____

____

____

Page Break

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

Q82 Please indicate which equipment you plan to use and things you plan to do today (select all that apply)

- ▢ 3D Printers or Scanners (1)
- ▢ Metal Room (CNC, waterjet, drill press, etc.) (17)
- ▢ Craftland (vinyl/paper cutter, sewing machine, foam cutter. etc.) (2)
- ▢ Electronics area (oscilloscope, power supplies, soldering, etc.) (16)
- ▢ Wood Room (18)
- ▢ Handheld tools (drills, screwdrivers, etc.) (15)
- ▢ CAD Station/ Work bench (33)
- ▢ Lasercutter (6)
- ▢ Foam cutter (39)
- ▢ Study / Just hang out / Meet with a group (34)

☐ Get help or give help (35)

☐ Prototyping Instructor On Duty (38)

☐ Paint Booth (25)

☐ Other equipment or activities not listed here (please specify) (22)

____

Display This Question:

If Please indicate which equipment you plan to use and things you plan to do today (select all that... = 3D Printers or Scanners

And Are you completing the Entry or Exit survey? = Enter

*

Q83 Which **types of 3d printers or scanner** do you plan to use?

- ▢ Ultimaker 2/3 (white basic printer) (1)
- ▢ SLS Professional Printer (Formiga) (2)
- ▢ Formlabs Form 2 3D Printer (3)
- ▢ Stratasys 3D Printers (4)
- ▢ 3d Scanner - FARO Arm (8)
- ▢ Don't Know (9)
- ▢ Other (6) ____

Display This Question:

If Please indicate which equipment you plan to use and things you plan to do today (select all that... = Metal Room (CNC, waterjet, drill press, etc.)

And Are you completing the Entry or Exit survey? = Enter

Q84 Which **specific Metal Room tools** do you plan to use?

- ☐ Band saw (7)
- ☐ CNC Mill (8)
- ☐ Manual Mill (1)
- ☐ CNC Lathe (9)
- ☐ Manual Lathe (10)
- ☐ Drill press (5)
- ☐ Injection molder (11)
- ☐ Vacuum former (12)
- ☐ Waterjet (3)
- ☐ other (6) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

And Please indicate which equipment you plan to use and things you plan to do today (select all that... = Craftland (vinyl/paper cutter, sewing machine, foam cutter. etc.)

*

Q85 Which **specific tools in Craftland** do you plan to use?

- ▢ Embroidery machine (CNC sewing machine) (3)
- ▢ Hot wire foam cutter (5)
- ▢ Sewing machine (2)
- ▢ Vinyl/paper cutter (1)
- ▢ Other (4) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

And Please indicate which equipment you plan to use and things you plan to do today (select all that... = Wood Room

Q86 Which **specific tools in the Wood room** do you plan to use?

- ▢ Band saw (7)
- ▢ Belt sander (8)
- ▢ Cicular saw (9)
- ▢ Chop saw (4)
- ▢ CNC Wood Router (1)
- ▢ Drill press (2)
- ▢ Foam cutter (12)
- ▢ Planer (13)
- ▢ Router (11)
- ▢ Sander (6)
- ▢ Table saw (3)

☐ Other (5) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

And Please indicate which equipment you plan to use and things you plan to do today (select all that... = Electronics area (oscilloscope, power supplies, soldering, etc.)

*

Q87 Which **electronic tools** do you plan to use?

☐ Circuit board prototyping (1)

☐ Multimeter (2)

☐ Power supplies (3)

☐ Soldering Station (4)

☐ Other (5) ____

Display This Question:

If Please indicate which equipment you plan to use and things you plan to do today (select all that... = CAD Station/ Work bench

And Are you completing the Entry or Exit survey? = Enter

*

Q88 Which **areas** do you plan to use?

- ☐ CAD Station (1)
- ☐ Workbench / tables (2)
- ☐ Other (3) ____

Display This Question:

If Please indicate which equipment you plan to use and things you plan to do today (select all that... = Study / Just hang out / Meet with a group

And Are you completing the Entry or Exit survey? = Enter

Q102 What do you specifically plan to do?

- ☐ Study (1)
- ☐ Just hang out (2)
- ☐ Meet with a group (3)
- ☐ Other (4) ____

Display This Question:

If Please indicate which equipment you plan to use and things you plan to do today (select all that... = Get help or give help

And Are you completing the Entry or Exit survey? = Enter

Q89 What do you **specifically** plan to do today?

- ▢ Get help from another student (not a Prototyping Instructor) (1)
- ▢ Get help from a Prototyping Instructor (3)
- ▢ I plan to help someone else (2)
- ▢ Other (4) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

Q90 Any additional comments:

____

Display This Question:

If Are you completing the Entry or Exit survey? = Enter

Q91 **Thank you for your time!**

End of Block: Enter

Start of Block: Exit

Page Break

Display This Question:

If Are you completing the Entry or Exit survey? = Exit

Q92 What did you do in the Invention Studio today? Please list projects you plan to work on, tools you plan to use, etc.

____

____

____

____

____

Page Break

Display This Question:

If Are you completing the Entry or Exit survey? = Exit

Q93 Please indicate which equipment you used and things you did today (select all that apply)

- ▢ 3D Printers or Scanners (1)
- ▢ Metal Room (CNC, waterjet, drill press, etc.) (17)
- ▢ Craftland (vinyl/paper cutter, sewing machine, foam cutter. etc.) (2)
- ▢ Electronics area (oscilloscope, power supplies, soldering, etc.) (16)
- ▢ Wood Room (18)
- ▢ Handheld tools (drills, screwdrivers, etc.) (15)
- ▢ CAD Station/ Work bench (33)
- ▢ Lasercutter (6)
- ▢ Foam cutter (39)
- ▢ Studied / Just hung out / Met with a group (34)

- [ ] Got help or gave help (35)

- [ ] Prototyping Instructor On Duty (38)

- [ ] Paint Booth (25)

- [ ] Other equipment or activities not listed here (please specify) (22) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = 3D Printers or Scanners

And Are you completing the Entry or Exit survey? = Exit

*

Q94 Which **types of 3D printers or scanner** did you use?

- ☐ Ultimaker 2/3 (white basic printer) (1)
- ☐ SLS Professional Printer (Formiga) (2)
- ☐ Formlabs Form 2 3D Printer (3)
- ☐ Stratasys 3D Printers (4)
- ☐ 3d Scanner - FARO Arm (8)
- ☐ Don't Know (6)
- ☐ Other (9) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Metal Room (CNC, waterjet, drill press, etc.)

And Are you completing the Entry or Exit survey? = Exit

*

Q95 Which **specific Metal Room tools** did you use?

- ☐ Band saw (7)
- ☐ CNC Mill (8)
- ☐ Manual Mill (1)
- ☐ CNC Lathe (9)
- ☐ Manual Lathe (10)
- ☐ Drill press (5)
- ☐ Injection molder (11)
- ☐ Vacuum former (12)
- ☐ Waterjet (3)
- ☐ other (6) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Craftland (vinyl/paper cutter, sewing machine, foam cutter. etc.)

And Are you completing the Entry or Exit survey? = Exit

Q96 Which **specific tools in Craftland** did you use?

- ☐ Embroidery machine (CNC sewing machine) (3)
- ☐ Hot wire foam cutter (5)
- ☐ Sewing machine (2)
- ☐ Vinyl/paper cutter (1)
- ☐ Other (4) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Wood Room

And Are you completing the Entry or Exit survey? = Exit

*

Q97 Which **specific tools in the Wood room** did you use?

- ☐ Band saw (7)
- ☐ Belt sander (8)
- ☐ Circular saw (9)
- ☐ Chop saw (4)
- ☐ CNC Wood Router (1)
- ☐ Drill press (2)
- ☐ Planer (13)
- ☐ Router (11)
- ☐ Sander (6)
- ☐ Table saw (3)
- ☐ Other (5) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Electronics area (oscilloscope, power supplies, soldering, etc.)

And Are you completing the Entry or Exit survey? = Exit

*

Q98 Which **electronic tools** did you use?

- ☐ Circuit board prototyping (1)
- ☐ Multimeter (2)
- ☐ Power supplies (3)
- ☐ Soldering Station (4)
- ☐ Other (5) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = CAD Station/ Work bench

And Are you completing the Entry or Exit survey? = Exit

*

Q99 Which **areas** did you use?

- ▢ CAD Station (1)
- ▢ Workbench / tables (2)
- ▢ Other (3) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Studied / Just hung out / Met with a group

And Are you completing the Entry or Exit survey? = Exit

Q103 What specifically did you do?

- ▢ Studied (1)
- ▢ Just hung out (2)
- ▢ Met with a group (3)
- ▢ Other (4) ____

Display This Question:

If Please indicate which equipment you used and things you did today (select all that apply) = Got help or gave help

And Are you completing the Entry or Exit survey? = Exit

Q100 What **specifically** did you use?

- ▢ Got help from another student (not a Prototyping Instructor) (1)
- ▢ Get help from a Prototyping Instructor (3)
- ▢ I helped someone else (2)
- ▢ Other (4) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Exit

Q100 If you did not use the tools and features that you planned to, what caused your plans to changed?

- ▢ I used what I planned to (1)
- ▢ Why plans changed... (3) ____

Display This Question:

If Are you completing the Entry or Exit survey? = Exit

Q101 Any additional comments:

____

Display This Question:

If Are you completing the Entry or Exit survey? = Exit

Q102 **Thank you for your time!**

End of Block: Exit

A.2 End-of-Semester Survey Example with All Survey Logic Annotated

Start of Block: GT ID

Q121 **Consent form is below. Please read and then scroll all the way to the bottom to join the study.**

Q146 Informed Consent Redacted for Anonymity

Q125 Do you consent to participate in this study?

1. Yes (1)
2. No (2)

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

Q127

3. First name (6) ____

4. Last name (7) ____

Q93

5. Email: (3) ____

6. [Student ID] (5) ____

End of Block: GT ID

Start of Block: Maker Usage

Q36 Please indicate the academic year you started at [School B]

7. 2020-2021 (10)
8. 2019-2020 (11)
9. 2018-2019 (12)
10. 2017-2018 (1)
11. 2016-2017 (2)
12. 2015-2016 (3)
13. 2014-2015 (4)
14. 2013-2014 (5)
15. Before 2013 (8)

Q38 Did you transfer from another university?

16. Yes (1)
17. No (2)

Q40 What is your class standing by credit hours?

18. Senior (1)
19. Junior (2)
20. Sophmore (3)
21. Freshman (4)

Q42 For the next section of the survey we are investigating your involvement in university maker spaces. A university maker space is a location associated with your university, designed to give prototyping access to students. Maker spaces give students access to prototyping equipment such as 3D printers and CNC machines for personal and/or class projects.

Examples of university maker spaces at [School B]h include [two examples of other makerspaces at School B]

Q44 Select the statement that best describes your familiarity with university maker spaces

22. I have never heard of any university maker spaces. (1)
23. I have heard of university maker spaces but I have never used any of the equipment and/or resources. (2)
24. I have used a university maker space's equipment and/or resources. (3)

Q95 Which university maker space have you used before? Select all that apply.

1. [ME Makerspace] (1)
2. [Biomedical Makerspace (2)
3. [Electrical engineering Makerspace] (4)
4. [Aerospace Makerspace] (5)
5. Other (please specify): (3) ____

Q48 Are you or have you ever been a student volunteer or employee of a university maker space?

25. No, I have never been a student volunteer or employee of a university maker space (1)
26. No, but I am interested in becoming one (2)
27. Yes, **I was** a student volunteer or employee of a university maker space in a previous semester (3)
28. Yes, **I am currently** a student volunteer or employee of a university maker space (4)

Q50 Please indicate the number of semesters you have been a student volunteer or employee of a university maker space (if you have never been a student volunteer or employee, put 0)

____

Q52 Have you ever used a university maker space to work on any of the following types of projects?

Select all that apply.

6. Class projects (1)
7. Personal projects (2)
8. Research projects (3)
9. Entrepreneurial projects (4)
10. Club or organization projects (5)
11. Other (please specify) : (6) ____

Q54 During **this semester** ([Current Semester]), have you used a university maker space to work on any of the following types of projects? Select all that apply.

12. Class projects (1)
13. Personal projects (2)
14. Research projects (3)
15. Entrepreneurial projects (4)
16. Club or organization projects (student competitions, SCC, SAE, etc.) (5)
17. Did not use this semester (7)
18. Other (please specify) : (6) ____

Q56 What organization(s) have you worked on projects for using maker space equipment? (Please list, separated by commas).

____

Q58

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

19. [Class A] (7)
20. [Class B] (8)
21. [Class C] (9)
22. Other (10) ____
23. Other (11) ____
24. Other (12) ____

Q60

During **this semester** ([Current Semester]), for which classes did you use a university maker space's equipment and/or resources? Select all that apply

25. [Class A] (7)

26. [Class B] (8)

27. [Class C] (9)

28. Other (10) ____

29. Other (11) ____

30. Other (12) ____

Q62 Have you ever participated in any of the following activities utilizing a university maker space?

Select all that apply.

31. Designing something (1)
32. Building something (2)
33. Fixing something (3)
34. Collaborating with other students in a project (4)
35. Helping students with their projects (5)
36. Teaching other students how to use some piece of equipment (6)
37. Advising students on how to approach a design problem (7)
38. Learning how to use a piece of equipment (8)
39. Participating in a university maker space related events (e.g. Ladies Night) (9)
40. Attending training session (10)
41. Other (please specify) : (11) ____

Q64 How much time have you spent **this semester** ([Current Semester]), during a typical week, in university maker space related activities?

29. None (1)
30. Less than 1 hour (2)
31. 1-2 hours (3)
32. 3-5 hours (4)
33. 6-10 hours (5)
34. 11-20 hours (6)
35. Over 20 hours (7)

Q66

In comparison to **previous semesters,** how would you rank the amount of time you have spent during a typical week **this semester** ([Current Semester]) in a university maker space?

36. I spent less time than previous semesters (1)
37. I spent as much time as previous semesters (2)
38. I spent more time than previous semesters (3)
39. This is my first semester being involved (4)

Q68 Please estimate the frequency in which you have been involved in university maker space related activities **this semester** ([Current Semester])?

40. Did not participate in any of the activities this past semester (1)
41. Daily (2)
42. 2-3 times a week (3)
43. Once a week (4)
44. 2-3 times a month (5)
45. Once a month (6)
46. Less than once a month (7)
47. Once a semester (8)

Q70 In comparison to **previous semesters,** how would you rate your involvement in a university maker space during **this semester** ([Current Semester])?

48. I was less involved than previous semesters (1)
49. I was as involved previous semesters (2)
50. I was more involved than previous semesters (3)
51. This is my first semester being involved (4)

Q72 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 maker space's equipment and collaboration areas during **this semester** ([Current Semester])? (Please enter the numeral, not spelled out number, e.g. enter "3" not "Three")

____

Q74 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?

52. I have worked on fewer projects (1)
53. I have worked on about the same number of projects (2)
54. I have worked on more projects (3)
55. This is my first semester being involved (4)

Q76 If you did not use the university makerspace as much this semester as previous semester or at all, why?

____

End of Block: Maker Usage

Start of Block: Tools Used415

Q126 Please indicate which tools and activities you used/did this past semester ("This Semester")

42. 3D Printers or Scanners (1)
43. Metal Room(CNC, waterjet, drill press, etc.) (17)
44. Craftland (Vinyl/paper cutter, sewing machine, foam cutter, etc.) (26)
45. Electronics Area (oscilloscope, power supplies, soldering, etc.) (16)
46. Wood Tools (18)
47. Handheld tools (drills, screwdrivers, etc.) (15)
48. Laser Cutter (25)
49. Cad station/ Work Bench/ White Boards (3)
50. Studied/ Just hung out / Met with a group (21)
51. Got help or gave help (4)
52. Prototyping Instructor On Duty (27)
53. Paint Booth (5)
54. Other equipment or activities not listed here (please specify) (22) ____

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Laser Cutter

Or Please indicate which tools and activities you used/did this past semester ("This Semester") = Paint Booth

Or Please indicate which tools and activities you used/did this past semester ("This Semester") = Prototyping Instructor On Duty

Q142 This last semester, how many times did you use/do the following tools/activities?

________ Laser Cutter (1)

________ Paint Booth (3)

________ Prototyping Instructor on Duty (4)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Handheld tools (drills, screwdrivers, etc.)

Q145 Estimate how many times did you use the following hand tools this last semester (Spring 2021)

________ All Hand Tools (1)

________ Hammers (2)

________ Pliers (3)

________ Vice Grips (8)

________ Clamps (C-clamp or other) (9)

________ Screw Drivers (4)

________ Hand Drills (5)

________ Angle Grinder (6)

________ Chisels (7)

________ Measuring Tape (10)

________ Table Vice (11)

________ Glue Gun (12)

________ Wire Cutters (13)

________ Hand Saw (14)

________ Dremel (15)

________ Tap & Dye Set (16)

________ Scissors (20)

________ Tin Snips (21)

________ X-ACTO Knife (22)

________ Other (please enter name and approx. # of times used) (17)

________ Other (18)

________ Other (19)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = 3D Printers or Scanners

Q128 Estimate how many times this last semester you used the following types of 3D Printers or scanners this last semester("This Semester")

________ Ultimaker 3 (7)

________ SLS Professional Printer (Formiga) (2)

________ Formlabs Form 2 3D Printer (5)

________ Stratasys 3D printers (4)

________ 3D scanner - FARO Arm (12)

________ Don't know (10)

________ Other (6)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Metal Room(CNC, waterjet, drill press, etc.)

Q130 Estimate how many times you used the following Metal Room Tools this last semester(Spring 2021)

________ Band saw (Metal) (7)

________ CNC Metal Mill (4)

________ Manual Mill (1)

________ CNC Lathe (9)

________ Manual Lathe (2)

________ Drill Press (Metal) (8)

________ Belt Sander (5)

________ Polishing Wheel (24)

________ Injection Molder (10)

________ Vacuum Former (11)

________ Waterjet (12)

________ Other (6)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Wood Tools

Q132 Estimate how many times you used the following Wood Room Tools this last semester(Spring 2021)

________ Band saw (wood) (7)

________ Belt sander (8)

________ Circular saw (9)

________ Miter (Chop) saw (10)

________ Jigsaw (11)

________ Drill press (wood) (13)

________ CNC Wood Router (25)

________ Router (18)

________ Planer (26)

________ Table saw (15)

________ Other (5)

________ Other (23)

________ Other (24)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Craftland (Vinyl/paper cutter, sewing machine, foam cutter, etc.)

Q136 Estimate how many times you used the following Craft Land Tools this last semester(Spring 2021)

_______ Embroidery Machine(CNC Sewing Machine) (1)

_______ Hot Wire Foam Cutter (2)

_______ Sewing Machine (3)

_______ Vinyl/Paper Cutter (4)

_______ Other (5)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Electronics Area (oscilloscope, power supplies, soldering, etc.)

Q134 Estimate how many times you used the following Electronics Tools this last semester(Spring 2021)

_______ Circuit Board Plotter (1)

_______ Multimeter (2)

_______ Power Supply (3)

_______ Soldering station (4)

_______ Oscilloscope (5)

_______ Logic Analyzer (6)

_______ Other (8)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Cad station/ Work Bench/ White Boards

Q136 Estimate how many times you used the following areas this last semester(Spring 2021)

_______ CAD Station (1)

_______ Workbench/ tables (2)

_______ White Boards (3)

_______ Other (6)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Studied/ Just hung out / Met with a group

Q138 Estimate how many times you did the following activities this last semester(Spring 2021)

_______ Studied (1)

_______ Hung out (2)

_______ Met with a group (3)

_______ Other (4)

Display This Question:

If Please indicate which tools and activities you used/did this past semester ("This Semester") = Got help or gave help

Q140 Estimate how many times you did the following this last semester(Spring 2021)

_______ Got help from another student (not a Prototyping Instructor) (1)

_______ Got help from a Prototyping Instructor (2)

_______ I helped someone else (3)

_______ Other (4)

End of Block: Tools Used415

Start of Block: 5-10 tool and the order you learned them

*

Q81 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?

56. 1 (1) ____

57. 2 (2) ____

58. 3 (3) ____

59. 4 (4) ____

60. 5 (5) ____

61. 6 (6) ____

62. 7 (7) ____

63. 8 (8) ____

64. 9 (9) ____

65. 10 (10) ____

Q146 Think about the tools you learned this last semester (Spring 2021) in the makerspace.

Please list as many as you can below

66. 1 (1) ____

67. 2 (2) ____

68. 3 (3) ____

69. 4 (4) ____

70. 5 (5) ____

71. 6 (6) ____

72. 7 (7) ____

73. 8 (8) ____

74. 9 (9) ____

75. 10 (10) ____

End of Block: 5-10 tool and the order you learned them

Start of Block: GT Tools learned Drag and Drop415

*

Q134 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 (68)
______ Lasercutter (6)
______ Ultimaker 3D Printer (19)
______ SLS Professional Printer (Formiga) 3D Printer (20)
______ Formlabs Form 2 3D printer (5)
______ Stratasys 3D printers (21)
______ Faro Arm (37)
______ 3D Printer (not sure which one) (1)
______ Band Saw (metal) (35)
______ CNC Metal Mill (28)

______ Manual Mill (25)

______ CNC Lathe (36)

______ Manual Lathe (26)

______ Drill press(Metal) (30)

______ Belt Sander (Metal) (65)

______ Polishing Wheel (66)

______ Injection Molder (38)

______ Vacuum Former (39)

______ Waterjet (11)

______ Bandsaw(wood) (15)

______ Belt sander (Wood) (2)

______ Circular saw (16)

______ Miter (Chop) Saw (27)

_______ Jigsaw (29)

_______ Drill Press(wood) (31)

_______ CNC Wood Router (18)

_______ Router (42)

_______ Planer (41)

_______ Table saw (32)

_______ Embroidery machine (43)

_______ Foam Cutter (44)

_______ Sewing Machine (40)

_______ Vinyl/Paper Cutter (67)

_______ Circuit Board Prototyping (51)

_______ Multimeter (52)

_______ Power supply (53)

______ Soldering Station (54)

______ Oscilloscope (55)

______ Logic analyzer (56)

______ Other equipment not listed here (please specify) (22)

*

Q136 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 (3)	______ Hand Tools (3)

_______ Laser Cutter (19)

_______ Ultimaker 3D Printer (4)

_______ SLS Professional Printer (Formiga) 3D Printer (20)

_______ Formlabs Form 2 3D printer (5)

_______ Stratasys 3D printers (21)

_______ Faro Arm (1)

_______ 3D Printer (not sure which one) (35)

_______ Band Saw (Metal) (37)

_______ CNC Metal Mill (28)

_______ Manual Mill (25)

_______ CNC Lathe (36)

_______ Laser Cutter (19)

_______ Ultimaker 3D Printer (4)

_______ SLS Professional Printer (Formiga) 3D Printer (20)

_______ Formlabs Form 2 3D printer (5)

_______ Stratasys 3D printers (21)

_______ Faro Arm (1)

_______ 3D Printer (not sure which one) (35)

_______ Band Saw (Metal) (37)

_______ CNC Metal Mill (28)

_______ Manual Mill (25)

_______ CNC Lathe (36)

_______ Manual Lathe (26)

_______ Drill press(Metal) (30)

_______ Belt Sander (Metal) (67)

_______ Polishing Wheel (68)

_______ Injection Molder (38)

_______ Vacuum Former (39)

_______ Waterjet (11)

_______ Bandsaw(wood) (15)

_______ Belt sander (2)

_______ Circular saw (16)

_______ Miter (Chop) Saw (27)

_______ Jigsaw (29)

_______ Drill Press(wood) (31)

_______ Manual Lathe (26)

_______ Drill press(Metal) (30)

_______ Belt Sander (Metal) (67)

_______ Polishing Wheel (68)

_______ Injection Molder (38)

_______ Vacuum Former (39)

_______ Waterjet (11)

_______ Bandsaw(wood) (15)

_______ Belt sander (2)

_______ Circular saw (16)

_______ Miter (Chop) Saw (27)

_______ Jigsaw (29)

_______ Drill Press(wood) (31)

_______ CNC Wood Router (18)

_______ Router (40)

_______ Planer (45)

_______ Table saw (32)

_______ Embroidery Machine (33)

_______ Foam Cutter (43)

_______ Sewing Machine (44)

_______ Vinyl/Paper Cutter (65)

_______ Circuit Board Prototyping (51)

_______ Multimeter (52)

_______ Power supply (53)

_______ Soldering Station (54)

_______ Oscilloscope (55)

_______ CNC Wood Router (18)

_______ Router (40)

_______ Planer (45)

_______ Table saw (32)

_______ Embroidery Machine (33)

_______ Foam Cutter (43)

_______ Sewing Machine (44)

_______ Vinyl/Paper Cutter (65)

_______ Circuit Board Prototyping (51)

_______ Multimeter (52)

_______ Power supply (53)

_______ Soldering Station (54)

_______ Oscilloscope (55)

______ Logic analyzer (56)	______ Logic analyzer (56)
______ Other equipment not listed here (please specify) (22)	______ Other equipment not listed here (please specify) (22)

End of Block: GT Tools learned Drag and Drop415

Start of Block: Demographics

Q82 What is your current major?

Select one

76. Aerospace Engineering (1)
77. Biomedical Engineering (2)
78. Chemical Engineering (3)
79. Computer Engineering (4)
80. Electrical Engineering (5)
81. Industrial Engineering (6)
82. Material Science Engineering (7)
83. Mechanical Engineering (8)
84. Nuclear Engineering (9)
85. Other (Please Specify) (10) ____________________

Q84 Have you ever had a full or part time job?

86. Yes (1)
87. No (2)

Q86 Have you ever had an internship or co-op? Select all that apply.

55. Yes, I have had an internship (1)
56. Yes, I have had a co-op (2)
57. No, I have never had an internship or a co-op (3)

Q88 Are you or have you ever been a student volunteer or employee of a university maker space?

88. No, I have never been a student volunteer or employee of a university maker space (1)
89. No, but I am interested in becoming one (2)
90. Yes, **I was** a student volunteer or employee of a university maker space in a previous semester (3)
91. Yes, **I am currently** a student volunteer or employee of a university maker space (4)

Q90 Please indicate the number of semesters you have been a student volunteer or employee of a university maker space (if you have never been a student volunteer or employee, put 0)

____

Q92 What is your gender?

92. Please specify: (4) ____

93. Prefer not to disclose (3)

Q94 What is your race/ethnicity?
Select all that apply.

58. White/Caucasian (1)
59. Black or African American (2)
60. American Indian or Alaskan Native (3)
61. Native Hawaiian or Other Pacific Islander (4)
62. Middle Eastern (5)
63. Asian (6)
64. Prefer not to disclose (7)
65. Other (8) ____

Q96 Do you consider yourself to be of Hispanic, Latinx, or of Spanish origin?

94. Yes, Hispanic, Latinx, or of Spanish origin (1)
95. No, not Hispanic, Latinx, or of Spanish origin (2)
96. Prefer not to disclose (3)

Q97 What is the highest level of education completed by either one of your parents or guardians?

97. Did not complete high School (1)
98. High school/GED (2)
99. Some college (3)
100. Bachelor's degree (4)
101. Master's degree (5)
102. Advanced graduate work or Ph.D. (6)
103. Not Sure (7)

Q98 What organizations on campus are you a member/involved in? (i.e. students competitions, honor societies, etc.) (Please list, separated by a comma).

____

End of Block: Demographics

Start of Block: Did not Fill out Entry /Exit but did sign consent, why used space less

Q74 We had a number of students who did not fill out the Entry / Exit surveys as they used the Invention Studio and this could have occurred for a number of reasons. Why do you think you did not fill out the Entry / Exit surveys each time you used the Invention Studio?

____

____

____

____

____

Q75 If you did not use the Inventio Studio or you used it less than previously semesters, why?

____

____

____

____

____

End of Block: Did not Fill out Entry /Exit but did sign consent, why used space less

---

Start of Block: Additional Questions

Q99 Any Additional Comments:

____

Q100 Thank you for completing this survey!

End of Block: Additional Questions

APPENDIX B: RESULTS FROM OBSERVING ENTRY/EXIT SURVEY PARTICIPANTS

Participant	Enter	Observed	Exit
1	Formlabs Form 2, Workbench / tables, Study,Other- work on CAD for projects, I plan to help someone else	Formlabs form 2, Desk area/work station, studied, met with a group	Formlabs Form 2 3D Printer, CAD Station,Workbench / tables, Just hung out, Get help from a Prototyping Instructor,I helped someone else
2	Formlabs Form 2 3D Printer	Work station, form labs 2	Formlabs Form 2 3D Printer
3	Ultimaker 2/3 (white basic printer), Study, I plan to help someone else	3D Printer, work area	Ultimaker 2/3 (white basic printer), Studied
4	Sewing machine	3D Printer	Ultimaker 2/3 (white basic printer)

5	Manual Mill, Waterjet, Router,Table saw, Study,Just hang out	Wood Room, met with a group	Router,Table saw, Just hung out

APPENDIX C. COMPLETE TOOLING DIFFERENCES BETWEEN RESEARCH SITES

Table 17: Complete List of Tools at Schools A & B

Tools	School A	School B
Laser Cutter	X	X
Embroider Machine (CNC Sewing Machine)		X
Vinyl/Paper Cutter	X	X
Foam Cutter	X	X
Sewing Machine	X	X
Paint Booth	X	X
Hammers	X	X
Pliers	X	X
Vice Grips	X	X
Clamps (C-Clamp or other)	X	X
Screw Drivers	X	X
Hand Drills	X	X
Angle Grinder	X	X
Chisels	X	X

Measuring Tape	X	X
Table Vice	X	X
Glue Gun	X	X
Wire Cutters	X	X
Hand Saw	X	X
Dremel	X	X
Tap & Die Set	X	X
Scissors	X	X
Tin Snips	X	X
X-ACTO Knife	X	X
Dremel DigiLab	X	
Ultimaker S5	X	
Ultimaker 3	X	X
Ultimaker 2+ Extended	X	
SLS Professional Printer (Formiga)	X	X
Stratasys	X	X
Resin 3D Printers (FormLabs)	X	X
3D Scanner	X	X
Studio System Printer (Metal)	X	
Scanner-3D	X	
Band Saw (Metal)	X	X
CNC Metal Mill	X	X
Manual Mill	X	X

CNC Lathe	X	
Manual Lathe	X	X
Drill Press (Metal)	X	X
Electric Discharge Machine	X	
Polishing Wheel		X
Surface Grinder	X	
Injection Molder	X	
Vacuum Former	X	
Waterjet	X	X
Hydraulic Press	X	
Metal Shear	X	X
Welding Equipment	X	
Band Saw (Wood)	X	X
Belt Sander	X	X
Circular Saw	X	X
Miter (Chop) Saw	X	X
Jigsaw	X	X
Drill Press (Wood)	X	X
Table Saw	X	X
Planer		X
CNC Wood Router	X	X
Router - Hand	X	X
Sander - Hand	X	X

Vacuum Former	X	X
Circuit Board Plotter	X	X
Multimeter	X	X
Power Supply	X	X
Sodering Station	X	X
Oscilloscope	X	X
Logic Analyzer	X	X
CAD Station	X	X
Construction Station	X	
Workbench	X	X
Mobile HDTV	X	
Whiteboard	X	X

APPENDIX D: PLANNED VS. EXECUTED WORK

1.16 Entry/Exit Data

At the beginning of this work researchers intended to use Entry/Exit surveys to capture students day-to-day making habits and investigate how students used the makerspace differently over time. This involved two main types of analysis, first, comparing students' entry responses to exit responses to determine what students journey within a single makerspace session looks like. It was anticipated that students may make considerable deviations from the tools they claimed they intended to use, and those they actually ended up using. This proved not to be the case with students entry and exit responses proving to be fairly aligned. Accordingly, Entry/Exit surveys provided similar data to End-of-Semester surveys, but without all the rich demographic, academic, and other information that provides a more comprehensive image of how students are using the makerspace.

Lastly, Entry/Exit survey data was intended to capture how a given students making habits changed over time, by investigating what tools they used over many iterations of completing the entry/exit surveys. Unfortunately, the vast majority of Entry/Exit participants completed these surveys once, making it impossible to execute this type of analysis.

As a result, Entry/Exit data was only analyzed for the sake of validating End-of-Semester data, and to help bolster the claim that students' responses for these final reflection surveys are in fact indicative of their typical day-to-day use of the makerspace.

In future work there is certainly opportunity for interesting analysis into Entry/Exit data beyond validating End-of-Semester data. It would be valuable to increase the number of participants, as well as to incentivize students to take these surveys multiple times so that changes in making habits may be observed.

1.17 Tool Usage Data

Tool usage data has been analyzed extensively in this work by a variety of factors to understand the impacts of Covid, academic and demographic factors on how students use makerspaces. There are still many other demographic, academic, and other identifiers that are collected in the End-of-Semester surveys that tool usage data could be analyzed by. Due to how many of these factors there are not all of these factors could be analyzed due to time constrains. Factors whose impact on tool usage was <u>not</u> analyzed are listed below.

- Academic year
- Academic Major (Insufficient samples for most majors)
- Transfer Student status
- Parents level of education
- Prior making experience
    - Familiarity with campus makerspaces
    - Prior use of campus makerspaces
        - Level of involvement in prior semesters
        - Reason for prior use of campus makerspaces

        - Classes taken before the current semester that involved makerspace use
- Prior internship/co-op experience
- Prior employment experience
- Involvement in non-making extracurricular activities
    - Familiarity with makerspaces
    - Past use of specific makerspaces at students' respective institution.

1.18 Order of Tools Learned

At present data for the order students learn tools is only analyzed by school, largely in effort to capture how differences between school curriculums effect students learning habits in these spaces. There are many other factors of interest that would be interesting to investigate such as specific class involvement, academic year, and so on. Due to time constraints as well as a lack of statistical methods to analyze this data, this data was not explored as extensively as it could be, and largely remains a topic for future work.

APPENDIX E: MISCELLANEOUS FIGURES

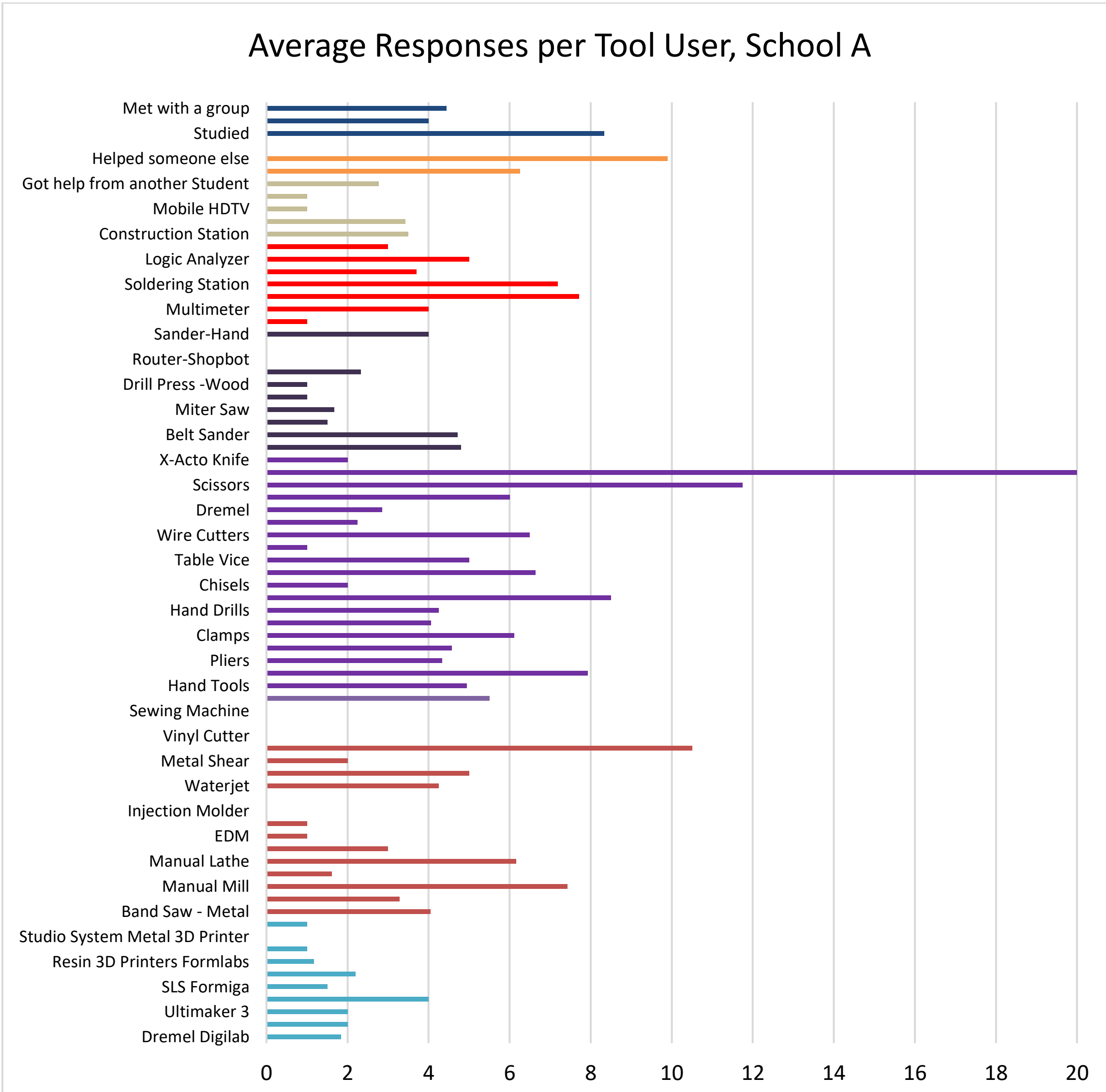

Figure 16: Average Responses per Tool User, School A, n=123, Spring 2021

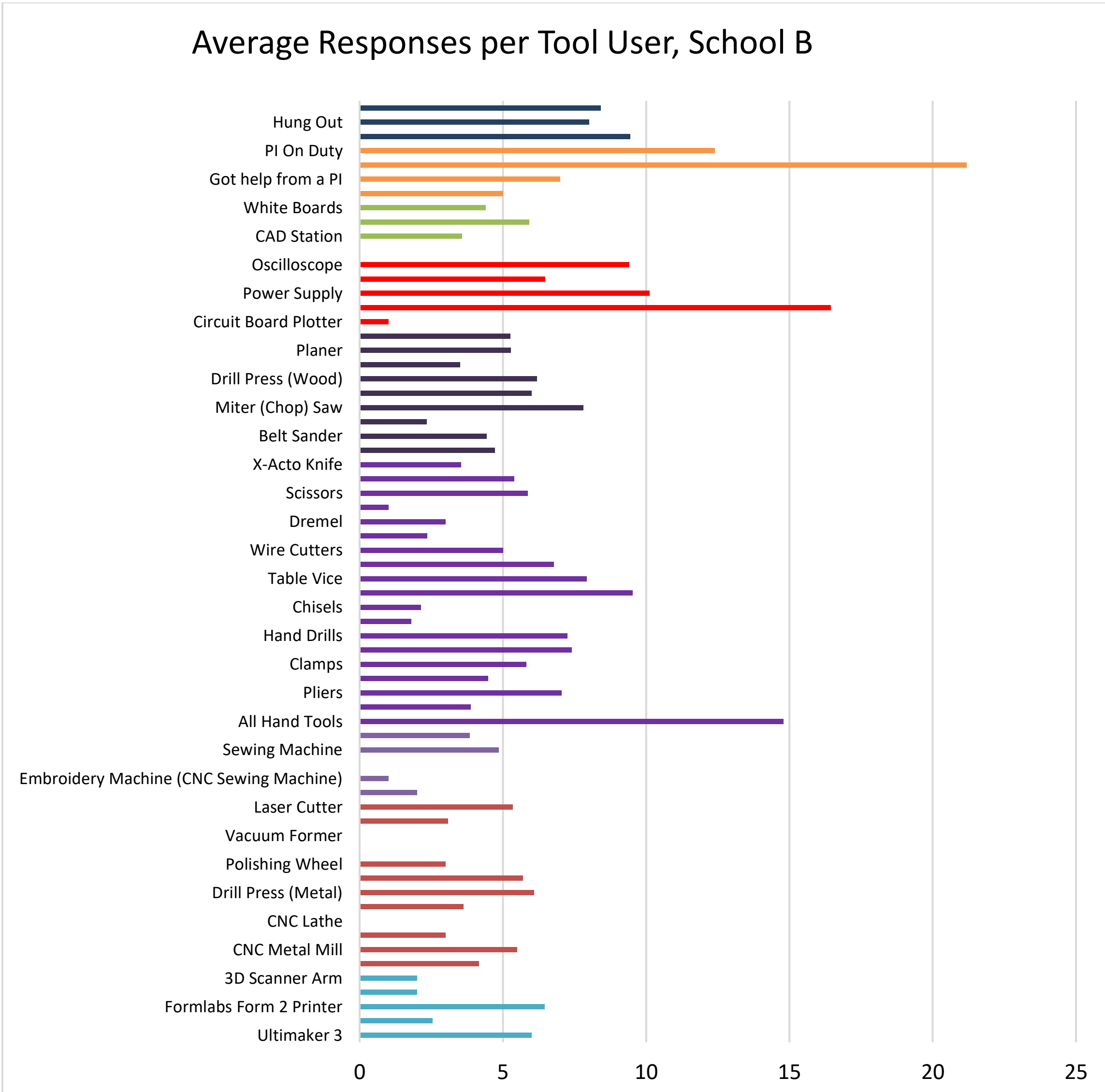

Figure 17: Average Responses per Tool User, School B, n=107, Spring 2021

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