Safety in a Student-Run Makerspace via Peer-to-Peer Adaptive Training

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INTRODUCTION

The Invention Studio at Georgia Tech is a free-to-use, student-run makerspace that serves the entire body of students and employees of the Georgia Institute of Technology. Campus makerspaces, such as the Invention Studio, provide a low barrier of entry to hands-on prototyping and fabrication experience relative to the classic machine shop model [1]. The student supervision of the space creates a unique environment that fosters campus community involvement in "maker culture", which is shown to have a positive impact in the professional development of students in S.T.E.M majors [2, 3]. Despite the numerous proven benefits offered by student-leadership in campus makerspaces, student-run makerspaces are uncommon, due in part to skepticism over the ability of student oversight to maintain a reliably safe workshop environment.

Founded in 2009, the Invention Studio has grown consistently in terms of staffing, space, and impact on campus culture. Without existing procedures to accommodate rapid growth, the Invention Studio developed a series of policies to mitigate administrative concerns over safety and quality of service. After the implementation of the checklist training program in 2014, the Invention Studio saw a decrease in the occurrence of recordable work-related injuries, as defined by OSHA [4]. These policies, which are described below and packaged in the appendices, may serve as inspiration to readers who are facing similar challenges with the growth of their own student-led makerspaces.

HISTORICAL BACKGROUND

Reacting to growing industry demand for engineering students with hands-on experience, the George W. Woodruff School of Mechanical Engineering at Georgia Tech created the Invention Studio in 2009. Initially recruited to oversee a small prototyping facility for the Capstone Design course, faculty champions selected ten volunteer student instructors for their prior experience in a machine shop environment. This tightly-knit group facilitated student access to tooling through peer-to-peer instruction while offering opportunities for non-academic tool usage to a limited number of people [3].

At this initial time, safety policies were mostly divulged by word-of-mouth through instructor/user interactions. Due to the limited number of available instructors and minimal advertising, a small, yet highly engaged user base emerged. To continuously provide course support over time, this group acquired new members primarily through targeted recruitment of skilled and trustworthy members of the regular user base. The process was informal, guaranteeing safety only through the accountability of the limited number of highly invested volunteers. As the Invention Studio began to attract increased traffic, capital investment, and campus attention, the volunteer staff prioritized an increase in the availability of open hours. The rapid rise in staffing requirements led to a mass recruitment effort, where the previously utilized method of accountability through recommendation was no longer an option.

Following a brief period where tooling and procedural information was lost through graduation of key early members and an increased concern regarding the safety of operations, the student leaders of the Invention Studio recognized the need for more sustainable, methodological training solutions to accommodate the diverse user groups. The first attempt at student-generated policy to address this operational gap was introduced in 2014, and can be seen in Appendix 1. These policies and procedures, which are the primary focus of this paper, established and reinforced the current distribution pathways for knowledge, shown below in Fig. 1. Prototyping Instructors (or PIs) are student volunteers who maintain the space. Support staff includes professional staff hired by the Woodruff School. As can be seen in the Appendix 2, safety track record has been excellent. There have been zero OSHA defined reportable injuries since the implementation of the policies and First Aid Kit Usage shows that the worst injuries were small cuts requiring a bandage.

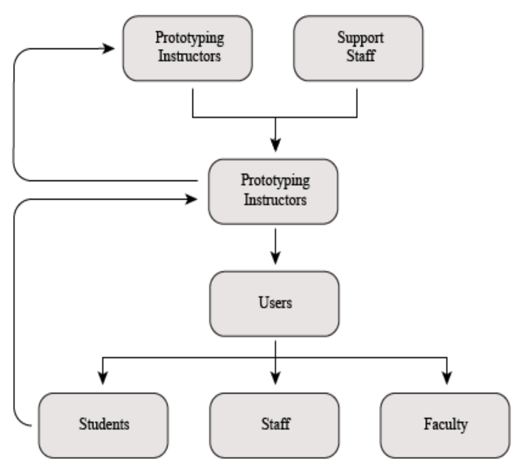

Fig. 1 Knowledge Transfer Pathways in the Invention Studio

A. *Various Users, Various Needs, Various Equipment*

Because the Invention Studio serves the entire population of the Georgia Tech campus, the user base is composed of individuals with various levels of hands-on experience, technical education, and project aspirations. Because of the need to minimize the barrier to entry for equipment access in the Invention Studio, users are not typically required to record demographic information, such as major, gender, or project type. The diversity of majors that participate in the space may be inferred by an analysis of the PIs. The Invention Studio's student leadership began keeping records of involvement since the Fall semester of 2012, despite operations since Fall 2009. In that time, over 230 students had served in an instructional or leadership role in the Invention Studio. Fig. 2 shows the majors of all recorded student volunteers in the Invention Studio over the past four years.

To date, student volunteers from 16 majors/disciplines have served as PIs. Note that abbreviations ending in "E" represent an engineering major, with mechanical engineering representing the most significant contribution of PIs. This can be attributed to the Invention Studio's location within a Mechanical Engineering building in conjunction with hands-on ME course requirements. Other strong sources of PIs include Aerospace Engineering, Biomedical Engineering, and Electrical Engineering. Members of other majors that do not teach CAD and traditional manufacturing methods - such as Chemical Engineering, Computer Sciences, and Human-Computer Interaction are also represented in the figure.

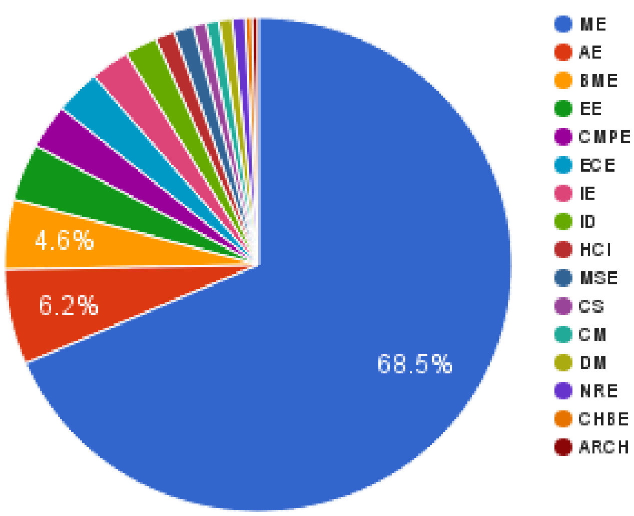

Fig. 2 Breakdown of Majors of All Recorded PIs

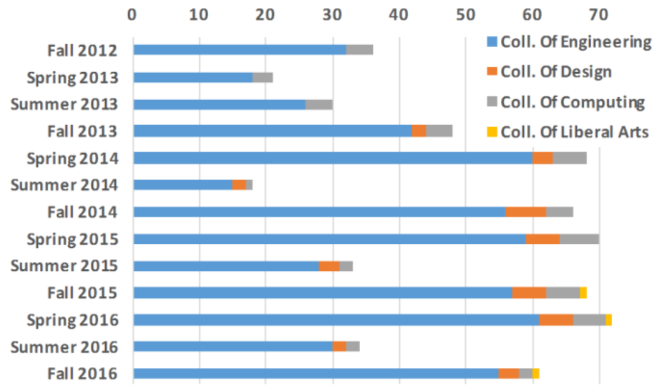

Fig. 3 Colleges of Active Prototyping Instructors per Semester

Fig. 3 illustrates the student involvement per semester by Georgia Tech. The number of active Prototyping Instructors fluctuates between semesters, with high turnout in the spring and fall, followed by a low participation in the summer, reflecting a campus-wide decrease in student presence. Four of Georgia Tech's six colleges have been represented in the Invention Studio's student volunteer base since Fall 2012, and participation of the College of Design and College of Liberal Arts is attributed to increased advertising and a campus-wide initiative for multi-disciplinary collaboration.

A wide variety of users require assistance with a broad range of projects - from holiday gifts to custom linear actuators. To successfully accommodate these project requests, the makerspace offers tools and equipment for processing many different methods and materials. As of the time of writing, the Invention Studio currently has six distinct categories of equipment, each with tools or features that require escalating levels of expertise and finesse. Examples of these categories and the tool offerings are shown in Table 1. Users are introduced to the appropriate tools and techniques for their projects as needed, but PIs generally train users on low-risk tools first. PIs who feel confident about the students' grasp of low-difficulty and low-risk tools provide additional training on higher difficulty tools, as listed below. Please note, the equipment list is not meant as an all-inclusive list of the available tools in the Invention Studio. Rather, it serves as an example of different training paths available.

Table 1 Equipment Available to Students by Difficulty Level

Tool type	Lowest Difficulty	Intermediate Difficulty	Highest Difficulty
Electronics	Soldering and Bread boards	Arduinos, Raspberry Pi programming	PCB milling machine
3D Printers	Afinia UP and UP mini	Makerbot Z18, UP box	Formlab, Hyrel
Waterjet	3 axis control	5 axis A-Jet technology	Advanced materials
Laser Cutter	Standard operating mode	Rotary attachment	Higher focal length lens
Wood-working	Handheld power tools	Planer, Table saw	Jointer, Wood lathe
Metal-working	Hand Tools	Metal Mill/Lathe	6 axis CNC

B. VARIED USER TRAINING OPPORTUNITIES

While access to equipment incentivizes participation of select users, the method of instruction delivery is key to creating a socially comfortable environment. Peer-to-peer learning has been shown to be beneficial in a classroom setting [5]. The Invention Studio takes advantage of the student-run aspect by creating a comfortable environment due to being taught by peers rather than traditional machine shop personnel. The comfort level is also increased by allowing the students to come and learn the equipment on their schedule. Rather than having structured and inflexible training times for students, the Invention Studio offers walk-in training on most of the equipment. To accommodate users who are not comfortable with the informal teaching methods, the volunteers in the Invention Studio offer structured training sessions on the equipment after normal studio hours.

Many times there are students who would like to learn the equipment but do not have a specific project in mind that they could use it for. For those students, the studio offers after-hours workshop events. These events serve to teach the students targeted equipment, ultimately working towards the same final goal of creating something they can take home such as a steel rose for Valentine's day. There are also events held for specific groups on campus, such as the "Ladies Night in the Invention Studio" for female engineering students. [6]

SAFETY AND TOOL TRAINING

C. PROTOTYPE INSTRUCTOR BASIC TRAINING

The perks granted to PIs, particularly 24/7 access to the equipment, prove attractive to many regular users in the space. Many students are inspired to become Prototyping Instructors, and therefore contribute to the culture of safety. To become a PI, the checklist program must be completed by recruits. A full copy of the Invention Studio current checklist at the time of writing can be seen in Appendix 3. The goal of the checklist program is to ensure a baseline competency for new PIs on all major equipment in the makerspace. The checklist does not indicate mastery or advanced knowledge of the equipment, but it does guarantee an understanding of safety protocols among Invention Studio PIs. The process was designed as a hands-on training tool, where the students learn through practice as has been shown to work in other instructional labs [7]. For each of the sections of the checklist, the potential PI must follow guidelines to create a specific object using key equipment in that category. For example, the woodworking task is to build the GT emblem shown in Fig. 4 by utilizing the relatively low-risk wood shop equipment.

Ideally, potential PIs have already spent time using the Invention Studio's equipment before attempting the checklist. However, if there is a tool they are unfamiliar with, they must get the appropriate training at least 24 hours before the start of that checklist item. This ensures that candidates do not simply copy what they have just been shown. In times of high machine traffic, students may seek supplemental information from the training videos created for the majority of low-risk tools in the Invention Studio. This "flipped classroom" technique exposes the students to an overview of safety guidelines and procedures, which allows for time in the studio to be focused on the details of practical machine use [8]. Because these videos feature the specific equipment available in the Invention Studio, students can draw directly from the lessons in the instructional videos when machine time becomes available. However, as Ian Charmas points out in his 2014 MakerCon presentation, videos can quickly become outdated [9]. Therefore, rather than solely relying on videos which require significant time, planning, and coordination to produce; an equipment and rules wiki-style site is monitored and populated by the Prototyping Instructors to serve as an up to date reference.

Fig.4 Woodroom Checklist Item

Once a potential PI feels confident enough in his or her knowledge, work on the checklist piece may begin. If they require help from the PI overseeing their room, the work done on the checklist task is discounted, and the recruit must retry that task another day. Following the completion of the task, the PI will compare the student's object with the sample object, and, if satisfied, he or she will sign off on that checklist item. The signature confirms that task was completed correctly, safely, and independently. Following completion of all checklist items and a brief culture-fit interview, the student assumes the role of PI, and begins overseeing the space, maintaining safety for the users and other volunteers.

D. *ADDITIONAL PROTOTYPE INSTRUCTOR TRAINING*

The training does not end once a person completes the checklist and is accepted as a Prototype Instructor. Because students are responsible for the upkeep and making equipment purchase recommendations, it is necessary to ensure specialized knowledge is transferred from one year's class to the next and is not lost when an expert member graduates. Each student has the option to specialize in any of the equipment in the studio to become a "master" of that tool. To do so, the student must complete the guided curriculum outlined by the current masters of their tool of choice (see Appendix 4 for example). The curriculum goes over how to repair the equipment as well as some of the nuances of the tools. Keeping with the theme of hands-on learning and makerspace culture, the apprentice student must complete a complex project using their newly mastered tool to prove their competency and finish their mastership training.

Another form of training offered to accepted Prototype Instructors is in an independent learning format called the "Maker Grant" program. Maker Grants are monetary grants given to any PI who wants to learn how to make a particular item using Invention Studio tools. The applicant PI must write a proposal outlining the budget, idea, and what he/she will learn from the experience. The premise behind funding personal projects is that if a student learns how to build a specific project, then they will be able to pass that knowledge on to the rest of the volunteer group and expand the library of knowledge that can be passed on to the users of the space.

RESULTS OF TRAINING

Efforts to appeal to as many different types of Georgia Tech students as possible have had outstanding success in attracting users and keeping them safe. As discussed previously, tools available in the Invention Studio are used by students and faculty from various engineering and non-engineering disciplines. As mentioned earlier, to keep the barriers to entry as low as possible, students are not required to sign in to use most equipment in the space, and this limits the ability to record demographic usage data. However, the professional printers and waterjet both require user input and therefore can be used to represent the usage of the studio as a whole. Fig. 5 shows the breakdown of unique users of the Professional 3D printers during last four years.

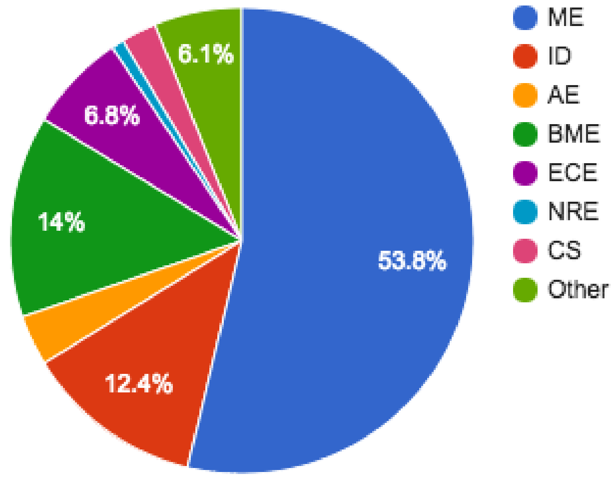

Fig. 5 Professional 3D Printers unique users by Student Major

As shown, approximately half of the total printer use comes from users outside the School of Mechanical Engineering even though the Invention Studio is housed in the mechanical engineering building. See Appendix 5 for a complete list of all majors and the amount of material used.

Besides accommodations for the user of any major, the Invention Studio prides itself on accessibility for a wide range of project possibilities. For diagnostic operations, one of the major tools, the waterjet cutter, requires logging of usage reasons in addition to standard equipment. Usage over the most recent semester, Summer 2016, indicates the diversity of usage in the Invention Studio. This data is shown in Fig. 6, and it provides a quantitative breakdown of the different uses of the Invention Studio. It is important to note that only 2% of the actual Waterjet use is for basic PI training. This exemplifies the impact the aforementioned training videos and other resources have to streamline the training process. Even during a semester with a low academic presence from decreased student population, equipment is still used regularly. Refer Appendix 6 for information on the daily usage of the waterjet from March 2016 to July 2016.

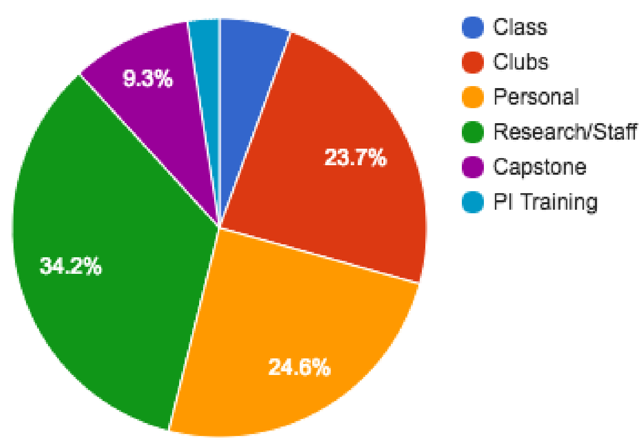

Fig. 6 Waterjet Usage by User Category

The instruction methodology of the Invention Studio seeks to enforce the diversity of projects and users that it naturally inspires. Through outreach events, space combats the pervasive issue of poor representation of females in STEM fields. Among the documented reasons for low female participation in STEM are a lack of opportunity, lack of role models, and a highly unbalanced male-to-female ratio [10]. Ultimately, those factors serve as barriers to hands-on familiarity by intimidation. Through the peer-to-peer training approach of the Invention Studio, some of that intimidation is mitigated. The Invention Studio has many strong female leaders who are Masters and PIs to serve as a role model. A biannual ladies' night hosted by the Invention Studio is specifically targeted towards women. The number of active PIs has doubled since 2013 due to these efforts.

Conclusion

The largest cause for concern in a student-run makerspace has always been safety. However, the case study of the Invention Studio shows that with the right training practices in place, a student-run environment can provide a genuinely safe and accessible learning environment. The student involvement and efforts of the Invention Studio have produced an open and welcoming culture for all Georgia Tech students ever since its conception. The specialized training for student volunteers keeps the equipment functional and mitigates the loss of knowledge from student graduation. The Invention Studio has been shown to be a safe environment through peer-to-peer adaptive training practices.

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