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# Evaluation of Undergraduate Staff Experiences and Infrastructure in a First-Year Engineering Makerspace

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## Introduction

In this evidence-based practice paper, we discuss an assessment of a makerspace for first-year engineering students, with a particular focus on the experiences of student employees. Makerspaces exist to support engineering programs at a variety of schools, and utilize a variety of management schemes. These spaces and their associated programming are sometimes managed or directed by faculty with student employees aiding in daily operation [1]–[3]. There are naturally ongoing conversations about best practices at academic conferences, and this paper contributes an additional set of practices, as well as a novel assessment of student employee experiences.

At Virginia Tech, well over 2000 students each year complete a two-semester general engineering program before selecting a specific discipline. The second semester general engineering course is dedicated to a hands-on design project. This project is supported by an academic makerspace accessible only to first-year engineering students. The makerspace has also historically provided students opportunities to pursue personal projects, and supported smaller projects run by some faculty as part of the first semester course.

The space is overseen by a faculty program director appointed from within the Department of Engineering Education, who receives course releases for this task. The appointment also includes a variety of departmental and university committee assignments. The operations of the space are the responsibility of a full-time staff manager. The leadership is supported by a staff of 35 part-time student employees, who are often hired based on the relationships they develop with existing staff while working on personal projects in their first year of study. Due to space constraints and the size of the first-year program, the team also supplies and manages tools and materials for the general engineering classrooms.

A variety of challenges and opportunities have arisen in recent years. The general engineering program has encountered significant and ongoing enrollment growth, more than doubling in size while continuing to use the same room dedicated almost 30 years ago. New university development plans are expected to increase enrollment further, and necessitate changes in preparation for a new planned dedicated space. The home department actively and continuously seeks to improve the first-year curriculum, and the leadership of the space must engage in those discussions and be able to adapt. Additionally, the challenges associated with COVID-19 and subsequent ongoing supply chain issues have created the need for multiple process adjustments.

In response to these challenges and opportunities, the makerspace faculty and staff conducted a program evaluation, and began a campaign of improvements and program expansions. Of particular interest was the student employee program, which had a reputation among the students for being very impactful. This paper describes the assessments of the student employee program, and of the infrastructure and management processes for the space, equipment, and materials.

## Literature

Recognition of the benefits of makerspaces in engineering programs has spurred their growth in universities across the country [4], [5]. These spaces provide a means for engineering students to gain design and build experience that is often overlooked by university engineering programs [6]. Such experience provides students the means to apply theoretical concepts learned in class to projects where hands-on learning experiences give students the means to encounter and overcome obstacles found in design build processes [4]. Some work has also posited that engineering students engaging in makerspaces have increased levels of confidence and critical thinking skills [7], [8].

In addition to design and build skills, makerspaces also provide students a venue for peer collaboration that fosters a sense of community [9], [10]. Prior research has also shown that continued engagement in makerspaces can be enhanced when students exhibit a sense of ownership over the space that is embodied by community values that spur the promotion of student creativity [11], [12].

Students get the most out of makerspaces when they are supervised by experienced staff [11], [13] and there are a number of staffing models that are employed in makerspaces. Student employees [3], graduate research assistants [2], faculty and university staff [4] are often employed to manage and supervise makerspaces. While there is abundant literature on the effect of makerspaces on students, there has been less research that focuses on makerspace student employees [3], [14].

One advantage of student staffing is that it supports peer mentoring, where first year students benefit from the sense of belonging instilled within the makerspace by upper-class student employees [15]. Within the scope of higher education engineering education, it has been found that mentor/mentee relationships have reciprocal benefits [16]. Peer engineering student mentors also benefit from personal growth and skill development through acting as role models and providing emotional support to first year students [17]. Yet the mentor/mentee aspect of student engineering makerspace employees is understudied.

Prior research has studied student engagement in makerspaces with deductive literature-based constructs often serving as theoretical starting points. However, little literature exists on the impact of student employment in university engineering makerspaces. Therefore, we chose an interpretive qualitative path in our research with the intention of seeking an inductive point of departure [18] in our study of Undergraduate Makerspace Assistants (UMAs). Moreover, this work discusses an in-house assessment of our infrastructure and management, which the UMAs utilize and support. We provide an analysis of our experiences and lessons learned through that assessment.

## Methods

We approached assessment from two directions: a qualitative assessment of the program through our student personnel, and a detailed look at our processes through an informal but thorough approach intended to reveal best practices in streamlining management. These assessments used different methods and focused on different aspects of the space, but both contribute to a holistic evaluation of our program. While the methods and rigor regarding the qualitative research are outlined below, we acknowledge that our managerial assessment took an approach based upon common sense and basic spreadsheet analysis. We therefore will focus a majority of our method section on the qualitative aspect of our program evaluation, with a brief summary at the end of this section on our procedures for infrastructure assessment.

*Employee Assessment*

The aim of our qualitative inquiry was to understand the impact of our Undergraduate Makerspace Assistants (UMA) program on the student employees. As such, the research question for this work was simply: *What are the impacts of the UMA program on student employees?*

Our selected methods included the inductive path of thematic analysis as described by Boyatsis [19] to develop our codes and resulting themes, and we chose to represent our findings through a narrative approach [18]. We chose this path because we found it the most appropriate to answer our research question, while also providing rich detailed accounts from our subjects that we feel best represent our interpreted themes.

*Study Participants and Data Collection*

Our data was composed of transcripts from a focus group and field notes. Participants were selected through mass emails to all UMAs. Of the 35 UMAs, 9 volunteered to participate. Students ranged from first semester UMAs to seniors with three years of experience. The sample was consistent with the demographics of the entire population of UMAs.

*Focus Group Protocol*

We took an interpretivist path in our data collection protocol, employing open-ended questions intended to reveal the experiences of UMAs. Our questions were framed to bring about a broad discussion on the impact of their experience with the makerspace, being an employee there, and their duties. As an example, one question was: “What thoughts come to mind when you think about being a UMA in this engineering makerspace? I’ve heard you mention x and x- please tell me more about that”. The focus group had a predetermined time frame of one-and-a-half hours and was audio recorded for later transcription. For more information on the stages that guided the focus group see [20, pp. 212–242].

*Data Analysis*

Data was first transcribed by one researcher, and then two researchers independently coded the transcripts. Several follow-up meetings allowed for a collective final agreement on codes, themes, and representative quotes that best illustrated the outcome space. In some cases, minor edits to quotes were made to improve clarity for the reader.

A necessary step in assuring quality of inductively interpreted data is to assure the raw data is applicable to interpreted codes [19]. While the researchers were mindful to practice reflexivity throughout data analysis, member checking took place individually with UMAs. Codes and relative themes were then discussed with the manager of the makerspace, who was also a UMA prior to graduating and assuming the manager position. As an additional measure of rigor after adjustments to codes and themes in the preliminary measure of quality assurance, we shared our anonymous data and findings in a meeting with four experienced senior UMAs and received final input. These measures informed slight revisions of the original codes and themes before we wrote our final report.

### *Infrastructure Assessment*

The assessment of process and logistics began with a methodical review of existing equipment, purchases, and processes. Data sources included budgeting and expenditure documents, as well as personal experience of the manager, who had worked in the space for years before being hired for that position. Opportunities for additional data collection were also identified and implemented.

Our space provides raw materials to students, paid for by their student fees. We supply a large volume of materials for the various tools and machines. For this assessment, we compiled a list of all materials we used and the associated volume, standard sizing and packaging, and pricing data. For each item, we identified alternative materials and sizing, and identified additional tools that would be required for processing changes, and compared costs.

We also did a methodical review of our processes, identifying the ways in which we were unable to adequately serve our students, and where the weak points and opportunities were. This was done through multiple discussions, and also based on unresolvable requests from students. We considered process alternatives, additional staff, and additional expenditure as elements of solutions.

## Results & Discussion

The UMA and infrastructure assessments were distinct, and as such, the results are presented separately. In each section, we discuss the results of the assessments, along with some actions that were taken as a result.

### *Results of UMA Qualitative Study*

The intent of the qualitative piece of our study was to develop an understanding of how the UMA program impacts student employees. Our findings revealed the formation of a strong community of student employee makers and mentors. Working in the space was widely seen as a defining part of the employees' undergraduate experience, and allowed them to engage in the hands-on skill-building activities that they felt should characterize engineering. The major themes of the UMA job as interpreted by the researchers were engineering skills, mentorship, and community (Table 1).

Table 1: Major themes of the UMA experience

| | |
|---|---|
| Technical Skills | UMAs prize technical skills they learn from doing their personal projects and see themselves as having knowledge that exceeds that of other engineering students. |
| Mentorship | UMAs see themselves as actors in a cycle of mentorship, and place high value on both providing and receiving mentorship. |
| Community | UMAs form strong bonds when working together and often socialize outside of working hours. |

These themes are hierarchically interconnected (Figure 1). The hierarchy representing the impacts of being a UMA is driven by the sense of community, where mentorship facilitates technical skill development. The following narratives further illuminate the "clusters of meaning" [18, p. 79] that represent our interpreted themes relating to the impacts of the UMA program on student employees.

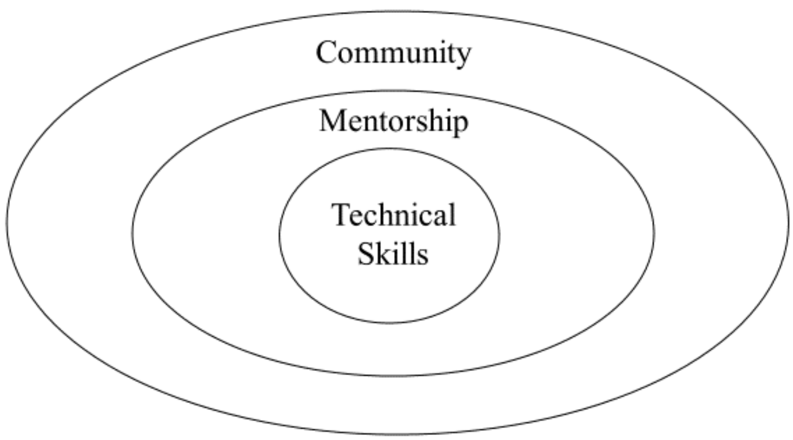


Figure 1: Hierarchy of impacts

*Technical Skills*

The makerspace is dedicated to foundational engineering education and the development of hands-on engineering design skills, and thus engineering skills were mentioned throughout the focus group. The space has a wide variety of tools and materials, and employees are encouraged to actively learn and use them all in order to more effectively help the student users. Subjects indicated not only that the space was successfully supporting this skill development, but also that it was an important part of being a good employee:

> "There's so much machinery that people have never seen before, and it opens up so many more things that they can do. There are things you would have thought would take ages

> to make that you can actually do in 10 seconds. You can do so much more just through the access to all the tools we have."

> "We learned how to use all these machines and we learned how to teach other people how to use them. [It's like the old saying,] if you help someone else, you learn it better. It's something you can put on your resume. And with CNC machines, laser cutters, and 3D printers, it's super impressive to have on there that you had the opportunities to mess around with them."

> "...the best of us are the ones that are coming in because they want to learn."

The focus group repeatedly stressed that the makerspace policy of promoting personal projects by both students and employees was further helping users to develop engineering skills, and indirectly expressed some concern about employees who don't make their own projects fitting in:

> "I think personal projects [are] one of the best ways we currently have of learning, and also definitely the biggest perk."

> "Engineering needs more than just doing a bunch of physics."

> "I talked to someone hired last semester, and asked them what personal projects they've made. And they said, oh, I haven't made any. They've been an employee for at least this semester, and they haven't done any personal projects. And that was not necessarily a good or bad thing, just different."

Because of the importance placed on these personal projects and their high training utility, the makerspace has increased the amount of advertisement to students of their ability to do such projects, and made it more clear that the provided materials are available for these projects for regular users and employees alike. We encourage employees to work on these personal projects when there are lulls in usage and no other tasks to be done. We have also begun promoting the job opportunity to our first-year students, and alert prospective applicants that one of the requirements for employment is spending lots of time in the lab working on personal projects.

*Mentorship*

Employees in the focus group talked about the impact of their mentorship experiences. This ranged from their time as first-year student mentees on through working in the makerspace as senior mentors. They indicated that a makerspace staffed with undergraduate employees led to peer engagement and mentoring, with significant positive outcomes for all.

> "My favorite part of the makerspace is… watching other people start to develop their skill sets and start to develop the realization that they can really build things."

Many students expressed that when they were first year students, they looked up to UMAs and wanted to be like them.

> "I looked up to senior people who worked there a long time who knew everything. And I was like, damn, I want to be like them. I want to know my way around this lab. I want to know what every tool does- and eventually get to that shift where it was like, I am one of those people. I love that I have the opportunity to be a mentor to the new employees and the students that come in, and it's really great to be able to share the knowledge."

Experienced UMAs mentor the younger UMAs during the learning process after they are first hired. So the aspect of mentoring is diverse and applies to not only the UMA to student relationship, but also UMA to UMA.

> "And I think that I've gotten better at helping people just from watching you [indicates senior focus group member]... You're really good at approaching and trying to figure out what it is that students want as opposed to what it is that they're asking.

UMAs are not afraid to ask other UMAs for help when they are learning about how to use equipment. There is no ego in the lab.

> "You can always ask another employee how to use this machine... And it's really a caring environment where you can learn. You can be totally honest."

In response to this positive feedback, we are actively seeking ways to expand the student employee program, and create more opportunities for the professional growth of our employees. We have been adding programming to create more informal mentorship relationships between the employees and new users.

*Community*

Community was the most dominant theme that emerged through our interaction with data. During member checking our initial findings, it was even expressed that "you can't take community out of any aspect of being a UMA". The mentorship relationships and personal project efforts have led to the formation of a strong sense of community among the UMAs. This is supported by the use of a Discord server, used both for official communication and organization, and for unofficial social and show-off purposes. The community of UMAs work and play together, and maintain friendships. They share core values of making things and helping each other learn how to more effectively make them. This theme of community can also be seen in many of the quotes included in the previous sections.

> "When we started using Discord it helped us to feel like a community. [Before that,] we had a GroupMe and it was like, does anyone want to trade shifts? [That's all we really said]. But now we have people showing off their projects or creating memes. And it's fun."

Personal connections between UMAs transcend standard work relationships, due to the sense of belonging that arises when working in the makerspace.

> "These are people that I do love. I love my coworkers a lot. So it's fun to actually be able to be friends with them, and have this sense of community. [I missed that during the

> COVID shutdowns]. Now I feel like I know you guys a lot more, cause we actually talk and we actually hang out."
>
> "There's a sense of belonging. When you're learning from someone, you start to respect them, not only their knowledge, but like, you know, they're caring for your projects. They care about the stuff that I care about, you know? And also it's just generally, a really nice community."

In response to learning about the unique sense of community between the UMAs, we have encouraged the things that it has grown around, such as personal projects. We are providing the space for after-hours fun activities for the UMAs, such as movie nights. We also have highlighted UMAs and their projects as part of the department's social media strategy to promote student engagement.

*Employee Feedback for the Makerspace*

The focus group uncovered some frustrations of the employees, such as with some older furniture, and a desire for some additional training support for some equipment. Most notably, they reported concerns about the first-year program instructional faculty not being familiar enough with the rules and capacities of the space and its employees. Due to the makerspace and classrooms being in different buildings, and the makerspace not being large enough to accommodate an entire section at once, a portion of the instructors had not been to visit since before the COVID-19 shutdown. Some students were coming to the space with unrealistic expectations such as immediate access to equipment training, or for the employees to walk them through entire project builds instead of offering guidance and suggestions, even during busy times. Students were blaming these misunderstandings on their instructors:

> "They frequently tell students to just go in and an employee will help you. They're passing the buck on to us... We are not TA's in your class. People come in asking questions about rubrics. And we cannot help them because we aren't given rubrics… And then they expect us to be able to deal with that. Like the amount of times I've had someone walk in and be like, can I drill a hole in this part for my project? I was told you could. And nobody told me you explicitly couldn't."

This suggested that the instructors might benefit from being provided with more specific language about the makerspace policies, and more active engagement and visitation. Since the focus group, the instructors have all been brought in for tours to see the new changes to the space and discuss its policies, and they have been invited to use it. The university's learning management system has a dedicated site for which all students and instructors have access, for which the language has been clarified. The student makerspace employees have also been visiting classrooms to share information, and we are experimenting with using them as teaching assistants.

*Infrastructure Review Results*

From an administrative level, the management team has developed many practices and solutions guided by years of experience as former student employees of the space and as program faculty. The staff manager, being a program alumnus and former UMA, had extensive first hand experience with pain points of the makerspace. Major areas of improvement included material sourcing, cost optimization, record keeping, and training. Other solutions were influenced by observations while in the management roles.

The first problems to be addressed were the ones with which management and staff already had experience. We looked for ways to make the space feel bigger, impress the students, and make processes easy to work within. The search was supported by metrics such as training capacity, cost per item, and number of times students encountered a specific problem. Vocal students and an engaged staff made this process review easier. Changes that resulted in more complaints were scrapped, and management reinforced operating procedures that yielded praise.

One of our most financially successful adaptations was in material procurement. As COVID-19 and global conflicts affected our plywood suppliers, we pivoted to buying bulk sheet goods and handling breakdown in-house. This decision has greatly increased the stock reliability, decreased the price per unit by ~75%, and completely covered the cost of a table saw purchased to perform the breakdown. Those improvements inspired more efforts into supply chain optimization allowing for expansion of materials/items/hardware offered to the students without substantial impact on spending.

Many of the solutions the team implemented required validation for assessment. This underscored the need for data collection and processing. A prototype sign-in system allowed for optimization of our website by tracking encounters with various errors. This system then evolved into a full-stack ecosystem that the manager can interface with remotely to see usage, tools in use, and more that influences staffing decisions and training scheduling. Efficiency gains from the sign in system helped justify the creation of two collaborations with another engineering department for senior design projects to automate an inventory database for the various locations where materials are stored or dispersed.

While numbers and performance indicators are useful when measuring the raw capacities and efficiencies of the lab, our team has found that the most effective means of finding ways of improving the space is by putting ourselves in our students' shoes and duplicating the projects they are expected to make. Only in doing the same projects as them, in our space, do we begin to see the bottlenecks that the students experience. We might discover that for a given project we need to cut a large curve in a thick piece of wood, which leads to a bandsaw purchase. We might experience bumping into someone while opening a supply closet, sparking a slight layout change to make the space more open. Identification of areas for improvement can be done by managers empathizing with users, and being one themself. In doing so, management is able to participate in continuous improvement discussions and prioritize changes.

## Conclusions and Future Work

This work presents an overview of a two-pronged assessment of a university makerspace dedicated to first-year engineering experiences. We discuss some opportunities for significant cost cutting and process streamlining in our infrastructure. We also demonstrate the value of engaging student employees in discussion about the space, and uncover unexpected benefits and areas for improvement. Makerspace employment has major impacts on skill development, creates fulfilling mentor relationships, and supports a strong community.

This work may be of use to other university makerspace directors, managers, and staff, particularly those with other competing responsibilities or little prior shop management experience. Moreover, we posit that program assessment using makerspace staff can provide meaningful insight into best practices in makerspace management. In our case, we not only established that the makerspace provides student workers with engineering skills, but also that the culture of the makerspace fosters personal relationships that have great value to student workers. Furthermore, we discovered that these relationships transcend the bounds of student workers through providing mentor/mentee relationships that positively impact the future of new engineering students entering the program.

We acknowledge that our findings are situated in a specific context. However, future and ongoing research will collect larger sets of data from student workers throughout their time in the program. Our goal is to produce future publications with more generalizable results. As a starting point, we have conducted a series of in-depth interviews with UMAs to explore their individual experiences, the mentorship phenomenon, and makerspace community formation.

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