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Resilience and Innovation in Response to COVID-19: Learnings from Northeast Academic Makerspaces

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Introduction

Studies over the last decade have emphasized the need for hands-on, experiential learning and the importance of making in engineering education [1-3]. This emphasis has led to the blossoming of makerspaces in engineering schools and universities more broadly [3, 4]. Academic makerspaces support both curricular and co-curricular design projects and learning at many institutions. As the Covid-19 pandemic has forced most universities to switch to fully remote or some combination of hybrid and remote courses, many of the physical activities necessary for prototyping are in flux. What has happened to makerspaces and how have they tried to maintain their key role in both co-curricular and curricular learning?

In Spring 2020, most shut down all in-person operations. The Fall 2020 semester has seen a whole gamut of models for classroom teaching and teaching labs. Many universities have allowed their labs and makerspaces to open in a limited capacity, but some have suspended all, or almost all, operations. To keep supporting the students they serve, academic makerspaces and the staff who run them have pivoted in crucial manners to the impact of the Covid-19 pandemic – from operational changes (access, hours, etc.) to new training methods, different ways to support prototyping and design, and additional online programming such as invited talks and workshops.

This paper presents an overview of common challenges to typical academic makerspace operation. Grounded on an exploratory interview-based study of makerspaces in four universities in the US Northeast, it highlights the changes and adaptations in operation due to Covid-19 as well as the innovations developed to support design and prototyping and continue to offer a supportive learning environment for students. Four main learnings emerged from the analysis:

1. Increased operational burden, complexity, and bureaucracy
2. New roles for managers
3. Continuity of staff training and the importance of informal, in-situ learning
4. Innovations in training, programming, and services

These are discussed and highlighted in the cases below.

Background

Academic makerspace use has become embedded in many design courses across engineering schools, from first-year cornerstone, through new and innovative experiential programs, to senior design and graduate study. These spaces have served as a vehicle for curricular reform, encouraging engineering faculty and departments to require or embed

more hands-on experiential learning. This usage can take many forms, with some courses operating within the makerspace itself, some requiring usage of the makerspace or certain prototyping equipment, and others tangentially connected as a resource for design projects [3-6].

Across the literature, there is an emphasis on the importance of community development and culture in these spaces for collaboration and multidisciplinary learning. Some researchers have studied this growth as communities of practice, with shared interest in making and design projects among the users of the space, and core users who encourage peripheral participation and engagement. Student users learn by observing how others engage with makerspace resources and by asking in-situ questions, where that learning is a function of activity, context, and the culture in which it occurs [7].

Other researchers have looked at the impact of a culture of personal responsibility and ownership within a makerspace [7-10]. Limited capacity and limiting in-person interactions may naturally dampen community development in makerspaces. Managers and researchers should look at how to best support collaboration as operations and capacity resume.

Some academic makerspaces have utilized hybrid training models before the pandemic, but not many. These spaces previously focused on the development of online training modules or courses through the school's learning management system (LMS) to help with staffing challenges and training time [11]. However, in the majority of academic makerspaces, training has historically been conducted in person [9,10].

In a forthcoming paper looking specifically at the impact of the Covid-19 pandemic on several digital fabrication courses, it was found that some students had additional opportunities to explore and iterate in their homes. However, this was dependent on the students' access to tools and equipment, and the pandemic was shown to exacerbate some inequities in experiences and resources [12]. While availability of an academic makerspace within a school can normally limit the burden of acquiring such tools and equipment, there is little information yet available on how makerspaces have reacted and pivoted due to the pandemic and the impact on student design projects. Academic makerspaces will continue to have a role to play in supporting situated learning and unstructured learning.

Setting and Methods

This paper presents four case studies of academic maker spaces. Three of the four institutions are public, while one is private. The spaces have been open from three to five years, and three are directly supported by or housed in the school of engineering, while the other one by the school's IT department. All four makerspaces were previously open to users from across the entire university.

In 2018, a community of practice was established between the case study locations and 6-8 other regional makerspaces, with members regularly meeting to share ideas and initiatives [7]. This community continued to develop over 2019 with a yearly day-long meeting and intermittent emails. In 2020, during the early days of the pandemic, the community of academic makerspace managers began to meet monthly to discuss PPE production and makerspace operational recommendations.

Over March 2020 - February 2021, this community of practice had nine regular meetings to continue to share practices about how each space reacted and pivoted to pandemic changes. Several new members from local academic makerspaces were included in the meetings as they progressed, reflecting a growing and true community of practice with differing levels of interaction and involvement. The first author co-hosted these meetings.

The methodology used for this exploratory study is a qualitative approach, combining in-depth ethnographic interviews and a "diary" [13]. Interviews were conducted over January and February 2021 via Zoom. Questions were created based on an ethnographic interview framework, using descriptive and structural questions to describe operational changes and spur reflection [13]. Recordings of each interview were used to generate transcripts. The fourth case study was developed using the notes written by the first author on their experience as a manager of the space from March 2020 to March 2021 and monthly debriefing meetings between the two co-authors to discuss the situation of the makerspace and reflect on the first author's experience. The interviews and diary notes were analyzed inductively to define emerging themes. These themes were discussed by the two co-authors and put in perspective with the themes discussed during the meetings of the academic makerspace meetings. Based on the interviews and diary notes, the first author developed four case studies. The first and second author reviewed the case studies to compare and contrast them. Four themes emerged from this analysis and are illustrated in the case studies.

Case Studies

Makerspace #1

The first space is located in a public research university, physically located within several smaller rooms in a school of business building. The manager of this space was hired through the school's IT department, but also reports to the provost. The rooms are categorized as:

- Ideation and meeting space (greenhouse)
- Laser and power tools room (toolbox)
- Drill press and bandsaw room (shed)
- Recording studio

Before the pandemic, this makerspace was open to the entire university. The hours varied during the week but were generally 10AM – 5PM with a few weekend hours. In addition

to the manager, there was an additional full-time staff member who split their time 50% with the makerspace and other IT services, and 45-50 student employees. The manager had created a large team structure for student staff, with sub-teams who focused on different aspects of operational support and student team leads. After training from the manager, graduate students led faculty course prototyping and training requests.

Covid-19 and ongoing: In Spring 2020, the space was closed and the manager led PPE production, mainly face shields. All student staff were offered the option to work remotely to finish out the semester. The manager of this space was approved to hire only four students for this academic year to support curricular prototyping needs. This academic makerspace has currently not re-opened for general student use.

This makerspace directly supported faculty design and training requests. Previously, there had been a structure in place to handle those requests, with a graduate student taking the lead:

> "Before Covid, [faculty] would reach out to the makerspace… [and] I had a graduate student who handled [these requests]. They would meet with the faculty member [to] would understand what their objective was, and they would review syllabi. They would go through and work with specific [student staff] to make sure that training and projects were timed right… I wouldn't be involved at all. Post-Covid, [faculty] are directly reaching out to me."

Looking forward, this manager reflected on tensions caused by the lack of student support and how he hoped to build this back into his team structure. When asked if he would create this type of graduate student role in the future, he responded:

> "I think I need to. It was a push from a previous supervisor… That continuity for a year helped to deal with [the design process] if I was out or sick. They learned enough about me and my decision style to [feel comfortable] making decisions. It helped to streamline the organization. **I don't like being a bottleneck**." (Emphasis in bold added by the authors).

When asked to reflect on operational changes he might continue to utilize in the future, the manager of this space indicated that touchless sign-ins would be kept. However, he worried about changing the ways of greeting newcomers to the space. Indeed, previously, he had always instructed his student staff to shake hands, "making a physical connection [enables students] to go back up to [the staff] and ask questions about safety" and created an equalizing physical connection to the new environment. He emphasized the importance of these informal interactions in building a welcoming atmosphere in the makerspace but struggled to envision how that might look post-pandemic.

Discussing how he might plan to re-open the makerspace, he emphasized the need for training and building back the team from scratch:

> "At this moment, I will only have one continuing student who has been on the peripheral of the operation… I'm going to have to rebuild from scratch. I'm

> starting to think about how we do back end operations first – what I mean by that is, how do we build a redundant [student] lead or manager besides me since I'm a one-person operation? Get them on board, and then hire someone who has a breadth of operations from the facilities side. If I get approval, I'll try to hire those students over the summer, and then [work with them] … to begin hiring process to find the right team… I might only open the ideation space first, since it needs less [technical] skillset, and then start ramping space by space [later in the semester] … As I open spaces, not every [equipment] service may be available. It's going to be problematic."

Further elaborating on his potential plans for training over the summer, he continued to emphasize customer service training and slowly growing the student staff skills:

> "Training, the thought is, it would have to be over multiple days or more. First talking about growth and culture… culture building one day, a customer service and interaction half-day [training], and then starting to give them basic, generic [technical] services training without going in depth, and then over time starting to see which students can go in depth and specialize."

This manager has been able to work in the makerspace a few days per week to address a very limited amount of 3D printing requests from faculty. The space is potentially planning to re-open in Fall 2021. Overall, this manager focused on issues of training moving forward with a new student team and lack of peer mentorship and development caused by the pandemic closures.

Makerspace #2

The second space is within a public polytechnic university. It is managed through the school of engineering, and it is open to the whole university. Makerspace #2 is mainly arranged in a large open shop space, which is newly constructed. Machines are arranged by access level, with a variety of small hand and shop tools, 3D printers, a laser cutter, and electrical prototyping as "standard access" once a student attend training; additional laser cutter and larger shop machines requiring assistance from staff; and large CNC mills, lathes, and industrial 3D printers operated by staff only. Students or faculty who need parts machined could request via email. The space has two full-time staff members in addition to the manager and twelve students, 4 of whom were recently hired.

Previously the space was open Monday – Friday 12-9PM. Training sessions were only held in-person, with relatively large groups of students (20-30 per session) twice per week, led by the manager. After attending training, students would be granted RFID card access to the entrance turnstiles and tool chest. Once trained on further machines, students could use them on a drop-in basis. Faculty could also reach out via email for class prints, prototypes, or training, and this makerspace manager noted that they previously supported several courses directly including: capstone design in biomedical engineering, CAD courses in mechanical engineering, a first-year design course, and others.

Covid-19 and ongoing: During Spring 2020, the space closed and the staff were actively involved in PPE and face shield production. When describing the timeline for re-opening, the manager of this space indicated that student staff were actively involved in operational planning. Several faculty members were also involved "as consultants" in generating re-opening procedures and safety protocols. Over the summer, this makerspace operated a 3D printing service model built out in a project management software, where models could be printed and shipped to constituents who needed them.

This makerspace re-opened in Fall 2020. Hours were adjusted slightly to Monday - Friday 12-7:30PM to allow time to sanitize at the end of the night.

The manager described a list of the following safety protocols:

- Signage and PPE
    - Large poster with instructions at the front
    - Forehead scanner (placed by the school)
    - Acrylic barriers
    - Sanitizing table past turnstile barrier, PPE and cleaning supplies
    - Racks for bags - involved in sanitizing procedure
    - Can get chemistry goggles for free and bring in, or charge $1 for plastic safety glasses
- Procedural
    - One-way paths routed through the space
    - Work benches broken up for single use only
    - Utilize and sanitize space flash drives
    - Built in cleaning redundancies - clean machine before and after
    - Policies to close space if uncomfortable or too full

Student staff were encouraged to have ownership over the capacity as well. If the space was not at capacity but the staff deemed it to be uncomfortably full, they were encouraged to close the door and turn on a "no vacancy" sign they have at the front. Training is now a recording of the manager giving the training presentation, available on Canvas, the school's LMS, as a community course. Canvas allows the manager to generate a list of students who have completed the course, and it also has the option to embed quizzes. The manager of this space plans to record additional training sessions over the semester to host on Canvas.

When reflecting on Fall 2020, the manager indicated that usage had been low, and that the large number of steps in the safety protocols may have been confusing to students and a barrier to entry. This space has not instituted a reservation system, they "haven't hit a level of usage that necessitates [reservations]." Elaborating on this and the changes in his role, he said:

> "**I have been calling myself air traffic controller**… what I mean by that is, I get a shocking number of emails from students, faculty, and staff, asking for my permission to do things. So, this might have been the way it was before Covid, but

definitely now with the [new] protocols, **I get a lot of emails asking 'can I do this?'… I would say almost half, maybe more, of the usage of our space is a result of me answering an email in the affirmative**." (Emphasis in bold added by the authors).

Reflecting further on the changes in his role, he said:

> "I'm in my office more… I do get more work done, but the by-product of that is that I don't see the student workers as much. I can't give them as much guidance… I would like to actually go down on the floor and work there. I've noticed when I sit down there with them they are more productive."

All course utilization was reduced during the pandemic. During the interview, the manager shared that several courses had restructured assignment to limit in-person tours and training, design team usage was much lower, and that bandwidth for laser cutting restricted the usage of one new architecture course. Though this space is operational and open to students, challenges facing student staff development were highlighted. This manager emphasized the lack of in-situ training and tacit knowledge translation due to safety barriers and comfort.

Makerspace #3

This lab is housed in many small adjoining rooms in a building in a large, public R1 university, with the previous capacity of each of these rooms being 1-3 users. The space is managed by the school of engineering and open to all university students, staff, and faculty. Previously, this manager had one additional full-time staff person and 18-20 student staff members. The hours of operation used to be Monday - Friday 1-9PM.

In contrast to the other three spaces, this academic makerspace has offered a 3D print service for several years, perhaps due to physical distance on the large campus from other labs and buildings. There is a departmental email, which can be used to submit .STL files, because "every print submission needs a small conversation." Students would have then been required to pay before printing. When describing faculty and curricular support, this manager described several levels of engagement:

- "Official" class engagement: students would be required to attend a tour together and learn how to use specific machines or tools for their class project
- "Unofficial" class engagement, includes two levels: faculty would require makerspace usage for a course project by students in their own work time vs. faculty would mention that the makerspace was a resource for course projects but would not require usage

Covid-19 and ongoing: Conversations began with this manager and doctors at the school about PPE production in late February. The makerspace shut down to users in the spring, with some student staff still employed over the summer, and re-opened to general student use in Fall 2020. Due to the pandemic, the open hours are now Monday - Friday 11AM-

5PM, with student staff scheduled to work 10AM-6PM to have time to clean and disinfect. The staff of the space are expected to clean after each student user.

For this academic year, the front door is now locked at all times. Visitors must have a reservation and ring the doorbell to be let in. The manager reflected on this change in access and their reservation system, saying:

> "[Previously], I never heard the doorbell on our building, ever. Our front door was always open; people could walk in… Now, the front door is locked, and we're by reservation only. We've been using Microsoft Bookings to schedule literally everything, and it's really been great. I have a visual record on the calendar of what students are coming in to the buildings to work on what machines and when. **We're going to continue that moving forward even if we are able to do walk-ins**… At the beginning of the day… we have our agenda for the day of who is coming in when and who is going to help what, and it really helps to organize [the makerspace]" (Emphasis in bold added by the authors).

There are keyboard covers at the sign-in station and hand sanitizer stations. Because of the layout of this academic makerspace, the machine and room capacity has not changed very much: all reservations are individual. The 3D print service continued and was refined during the pandemic. Students can now pay at pickup and the manager is looking into online payment methods and contactless kiosk pickups. Similarly, this space had utilized online training before the pandemic. The videos are posted on Canvas, and additional online machine training modules have been created over the past year: laser cutting, wood shop 2, with embroidery machine and UV printing upcoming. Once a student completes the Canvas course, they can request the follow up hands-on training to get access, which is a 30 minute to one-hour training. This is scheduled by the manager himself and students would then have RFID access to that specific machine. Overall, this process has been expanded and improved over the past year: "we've expanded our reliance on that training since Covid, but mostly because I've had more time [at home] … where I can write curriculum."

Currently, there are five student staff members. The manager of this makerspace discussed his worries about skill and training turnover, mentioning that he typically hires new students each semester as needed, but has not been able to for the past year. He spoke about a high standard for student staff and organizing the space, which had perhaps been too relaxed while he was remote. Reflecting on future changes, the manager planned to keep his iterations on the remote 3D printing process, including online payments, and some of the protective barriers.

Required curricular usage ("official" faculty engagement) was reported to have declined slightly. However, this space's "unofficial" course project use was reported to be much lower than in previous semesters. The manager speculated that this was due to commitment level from faculty to embed makerspace usage in their curriculum. Several challenges in makerspace operation were created by the pandemic: limited informal

interactions between student staff hindered peer mentoring and additional complexity and bureaucracy were needed for access management. This academic year has allowed the manager to focus on refining their print service and pick up options, as well as training content and curricular development.

Makerspace #4

This academic makerspace is mainly comprised of a large open work and lab space. It is in a large, private university and managed by the school of engineering. In addition to the manager there are two full-time staff and 30-35 student staff. This space is open to the entire university. In-person training sessions were offered multiple times through the week – interested students could drop-in at the set time to attend the training – and sessions were mainly led by the student staff.

In addition, this makerspace regularly hosted technical and/or design focused workshops, which were usually 1-2 hours in length, and run by either the makerspace staff members or invited guests. Co-leading at least one workshop per semester is a requirement for all student staff. Previously the hours of operation were Monday – Friday 9AM-11PM, and Saturday – Sunday 12-6PM, and all trainings and workshops were help in-person only.

The first-year engineering program in this school required all students to attend the makerspace training as a pre-lab requirement. Faculty were encouraged to reach out to the makerspace if they were interested in setting up training sessions for their course, and many courses in the school of engineering directly required makerspace training or usage for design projects.

Covid-19 and ongoing: This space closed in March, with only full-time staff working on face shield and PPE production. Over the summer, student staff hires were approved to begin remote and limited in-person work to prepare for fall and support prototyping service requests from faculty and researchers.

This fourth makerspace re-opened for general student use in September 2020. A partial 3D print service was continued from the summer to allow for required course prints only, and a restaurant style reservation system was created for all machine and work space usage. The system was slowly rolled out over September, and it was fully operational by October as new student staff were onboarded and trained. The hours for this academic year have been slightly reduced to Monday – Friday 10AM-10PM, Saturday – Sunday 12-6PM.

A new hybrid online training system was created utilizing the school's video streaming service, which could include embedded quizzes and track views and participation through school ID. An in-person, socially distant component is still required for each training session, similar to makerspace #3. In addition, student staff were encouraged to have ownership in the development of this new system, with several senior student leaders spearheading important components and build out for the new reservation system.

Makerspace capacity was limited to roughly 40% of prior occupancy, with greatly reduced number of work tables and chairs. The reservation system and hybrid online training necessitated backend student support, with remote support students working to check training records daily. A partial 3D print service system was continued for specific required course prints (an additive manufacturing class, senior design) and for specialized resin prints. The first-year engineering program required students to view the online training for the makerspace, but could not require any in-person component as many students were fully remote. Senior design faculty in this school offered both remote and in-person design project options, which also limited required usage of the space.

Over the past academic year, new student staff in this makerspace did struggle to complete onboarding and gain confidence in their ability to train others. The manager of this space focused on additional structure for peer mentoring and allowing for additional time – several months – to complete onboarding training. A new set of advanced onboarding tutorials were created by a graduate student staff member over winter break and implemented in Spring 2021 to continue to grow technical and design skills.

During the start of the pandemic, this makerspace team pivoted to online workshop delivery. Workshops scheduled in Spring 2020 which required a physical component were transformed to focus on design software and demonstrations. Since then, all workshops have been virtual, as in-person gatherings and events are still cancelled. Online collaboration tools such as MURAL were utilized to encourage interaction during design focused workshops. Social media was used much more than in previous years to highlight student work, including working with student teams to generate video content to share on YouTube. There was large response in Fall 2020 to the workshops, with over 850 attendees, many from departments and schools within the university who would not normally participate.

All Spaces

Reflecting on the new training systems, programs, and services: at least part of each new operational system will be kept moving forward. Reservations for most machines and for training are planned for future operations, but tables, work space, computers, and entry level 3D printers will revert to drop-in use to support community development and ease of access. Hybrid training has been well received by current student users, but the additional operational burden to connect disparate systems needs to be diminished for the fall, most likely by automating the training checks between the systems.

All makerspaces had low utilization, with the managers sharing in monthly meetings that usage was far below even the reduced capacity. Innovative ways to control and provide access to this limited number of users were shared across spaces. Continuity of staff training and apprenticeship was likewise an issue for all of the makerspace profiled, continuing to highlight the importance of community and informal, peer mentoring in the development of academic makerspaces.

Discussion

Initial findings from all four academic makerspaces reflected changes in all of higher education: hybrid teaching and learning, new online modules or content, and reduced capacity with cleaning procedures and PPE. Academic makerspaces were quick to embrace new technology and used to approaching their operations as a design problem. Digging deeper into the impact on each space, several common themes were highlighted by all four managers as they reflected on the changes over the past year and a half.

Overall, the largest concern of all spaces was the continuity of training and knowledge sharing within their student staff. This had taken years to built up as an ongoing system with a mentorship structure: older TAs mentored new student staff and assisted the managers with training and community building. This speaks to the large emphasis on peer learning and teaching in academic makerspaces and highlights a pain point when these underlying systems are disrupted. Figure 1 displays a summary visualization of some of these points. Makerspace manager #1 indicted in ongoing discussions that he wanted to "build back better" by improving these training systems and focusing on customer service from day 1 with new student hires. Space #1 and #4 had previously utilized a team structure for the student staff, with sub-teams and student leaders. Both makerspace #1 and #3 were forced to severely limit their staffing, as can be seen in the summary in Table 1.

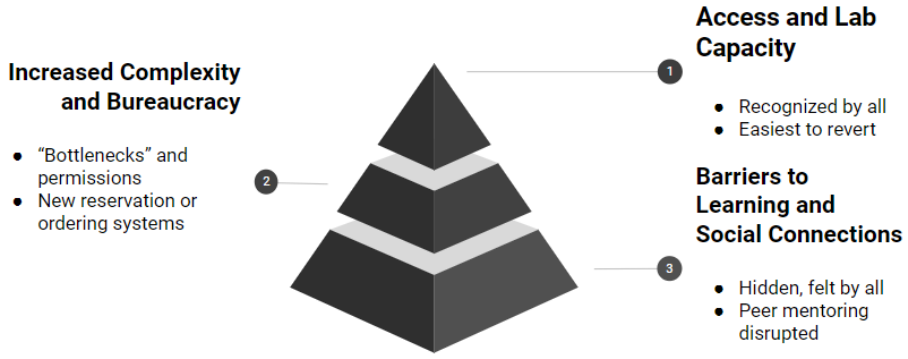

Figure 1: Makerspace Manager Pain Points

Likewise, all interviews included references to managerial tensions – in most makerspaces there is a balance between permission and supervision of new projects and ideas. In order to spur creative projects and intrinsic motivation, something usually embedded in the "culture" of these spaces, users are encouraged to have ownership of their design project ideas and, often, to be actively involved in suggesting new policies and procedures. Unconventional ideas are encouraged from student staff and student users alike. The managers of both space #1 and #3 indicated that they felt they were often a bottleneck for such projects, which required their sign off or approval to operate. This was brought up as an issue for both student printing requests and requests from faculty. In

order to facilitate as much curricular usage as possible as these spaces move back to a new normal, these bottlenecks will need to be addressed with additional support.

Table 1: Summary of Operational Changes

	Open	**Training**	**Prototyping Services**	**Staffing**
Makerspace #1	No	-	Yes, new	Highly reduced
Makerspace #2	Yes	Online	Yes	Same
Makerspace #3	Yes	Hybrid	Yes	Reduced
Makerspace #4	Yes	Hybrid	Yes, new	Same

Finally, reflection and continued iteration triggered continual change in all four spaces.

- Change in physical "welcome" or entry in to the makerspace
- Rapidly embracing technology and online training
- Building in resilience for return to "normal" – emphasis on in-person hands-on learning when possible

Designing the hybrid makerspace

Recent research has highlighted the key role the office played for work and how office spaces need to be considered when designing hybrid offices [14]. Similarly, from previous research, academic makerspaces are more than just providers of tools and resources. They play a key role in engineering education – in particular, supporting informal learning and tacit knowledge development, as well as in creating opportunities for unstructured collaboration [1]. The four academic makerspaces studied here were able to continue enact part of their mission – providing students some access to tools and resources (by implementing new operational procedures) in addition to training and skill sharing (via remote workshops and asynchronous videos). All four makerspaces were conscious of the need to find ways to experiment in supporting the less visible, yet essential dimensions of their role – informal learning and unstructured collaboration.

Limitations

The interviews conducted were built upon ethnographic interviews with makerspace managers but they do not include other actors (student staff and users, faculty) and they do not include any observations except in the fourth space. Additional interviews and observations, and ongoing collection of longitudinal data, are needed to further assess how specific makerspaces continue to evolve as the pandemic and country do.

Conclusion

As universities continue to move forward through the vaccine roll-out and prepare for future operational changes, academic makerspaces have a large part to play in student interaction, training, and support. In order to sustain and expand curricular and co-

curricular learning, academic makerspaces will need to strengthen the behind the scenes staff training and mentorship structure, and explore methods to empower new users.

Academic makerspace leaders should build support for the peer mentorship structure within their student staff. Leadership from the full-time staff and faculty who manage these spaces can emphasize customer service and community building while teaching technical skills. These can then be role modeled by student staff leads as they train younger staff and student users. Across academia, students who are returning from fully remote environments will need this additional support from their peers to encourage them to take advantage of makerspace resources and other informal collaborative learning opportunities such as clubs and professional societies.

Iterating on the new reservation and training systems that have been implemented during the pandemic can also work to remove long-term invisible operational barriers to entry or participation. For example, online and hybrid training sessions can accommodate different learning styles and allow for more targeted, hands-on training during follow up in-person sessions. Entering academic makerspaces can be intimidating to those who are unfamiliar with the tools and machines inside; enhanced online content better shows some of this hidden knowledge to newcomers. Continuing to offer a selection of workshops or events virtually can encourage interaction from schools or groups within the university who would normally not enter the physical makerspace. This participation can be nurtured to better support multidisciplinary collaboration and team formation in the future. Focusing on project documentation through social media and other virtual tools will help students learn how to make their projects more visible. While most students utilize social media already, few have developed project portfolios, and academic makerspaces can naturally demonstrate the value for career preparation and role model the development of better project documentation.

Moving forward, the authors hope to conduct follow up interviews for all four spaces as the university and makerspace functions continue to develop. To begin to assess the long-term impact on engineering student design skills, longitudinal studies from the first-year through capstone should be used. Many first-year engineering programs now utilize makerspaces, either embedded in the design course itself or by encouraging training and use of the larger school makerspace. Previously developed instruments could be utilized to look at impact on design self-efficacy with students who have access to an academic makerspace at different stages in their undergraduate career [15].

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