Co-Creating Opportunities for Extracurricular Design Learning with Makerspace Students

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Abstract

This paper details how student-led workshops can help nurture community in a makerspace and build design skills. Though both extracurricular design learning and peer-to-peer learning have been investigated in engineering education research, the combination of the two to promote a design thinking mindset and teach specific skills has not been fully developed. This paper details how this co-creation of extracurricular resources between peer teachers and faculty and staff mentors creates opportunities for students to learn prototyping and design-thinking to complement the more formal, in class engineering education. Student led workshops are presented as the start of a systemic series of extracurricular design learning experiences.

Introduction

The number of academic makerspaces has grown rapidly in the last five years. Many of these spaces focus on developing engineering design skills and nurturing a design thinking mindset by providing students with space, resources, and training. Extracurricular activities have been shown to play an important role in design and innovation learning, particularly in makerspaces [1]. Moreover, peer-to-peer learning in classroom and project-based courses like senior capstone design have been found to play a positive role in the development of design skills and mindset. However, research on peer-to-peer learning and best practices in extracurricular contexts is scant. This paper presents the use of peer teaching in an extracurricular setting and investigates how it can be used to develop a system to teach design and innovation outside of the classroom.

A series of design interventions in an academic makerspace are described which aimed to explore ways to teach design engineering skills and nurture a design thinking mindset among undergraduate and graduate students. The workshops had three major foci (technical, process, and interest-based) and involved four main actors (teaching assistants, student champions, student clubs and outside experts). The paper is based on the analysis of quantitative (survey data, data on participation to workshops) and qualitative (observations and interviews) data. The analysis supports the need for student champions to develop a community of practice and mentorship and structure for peer teaching topics and content in an extracurricular setting. Future work suggests a more structured series of design workshops.

Background

Extracurricular Design Learning

Research has shown the positive effect of extracurricular activities and projects on design learning. Dukart indicated strong findings that extracurricular project-based experiential learning

(EPBEL) experiences can have a positive impact on satisfaction in undergraduate engineering students, enhance their experience, and give them valuable skills [1]. These experiences rely on different pathways for students to find them and become involved. Yet, multiple challenges limit the access to these learning experiences: scalability, space and resources, 'white male privilege,' and the organization itself (for academic makerspaces this would be faculty and curriculum). Recommendations to cultivate these experiences included shared space, funding for projects, and faculty participation [1].

Gerber and colleagues, found that extracurricular design based learning (EDBL) support ABET outcomes and can strengthen self-efficacy in innovation tasks. Three sources of this increase in self-efficacy were identified: 1) mastery experiences, 2) vicarious learning, and 3) social persuasion. Using a modified Carberry instrument, it was found that the EDBL experiences studies supported the following ABET outcomes: "identify, formulate, and solve engineering problems; function on a multidisciplinary team; community effectively; and attain knowledge of contemporary issues" [2].

Peer-to-Peer Teaching

Many makerspaces are designed specifically to support or highlight design and interdisciplinary opportunities [3]. In addition, current engineering students are likely to work at smaller engineering firms or startups, which can serve as an impetus for entrepreneurial and innovation learning in the undergraduate experience. These skills are necessary for engineering graduates working in a startup environment [4]. Peer-to-peer learning is often introduced to teach these skills, learned in internships, research, or curricular opportunities. Such teaching can be cooperative – in a group – or one-on-one. Other examples of peer learning include more formal, curricular experiences, where students choose a topic, are mentored by faculty, and then present during the course [5]. Peer teachers often require mentorship, feedback, and practice; negative results for peer teaching highlight that students often lack the industry and engineering design experience to highlight or elaborate on certain points, and that students often do not know how to create active learning experiences in the classroom [5].

Peer-to-peer learning can also assist in development of critical problem solving skills as well as communication and collaboration skills essential to the design process [5]. Some researchers have started investigating the role of peer-to-peer learning in extracurricular design projects and have shown improved task-specific self-efficacy [2]. This research on peer-to-peer learning highlights the importance of developing a community of practice that can nurture the peer-to-peer learning experience which takes place not only during specific design project work and mentoring but also during informal interactions [2]. However, there are few papers on combining extracurricular design learning in a more structured format with peer teaching.

Community

Communities of practice, defined as collective learners in a shared domain, such as a group of engineers addressing a design problem or project [6], have been identified as central in supporting learning and collaboration in makerspaces [7], [8].

Yet, anxiety can still be a significant barrier for students to start participating in a university makerspace, and research can often be skewed by dedicated or highly active users [1], [9]. By nurturing a sense of community and a feeling of belonging, makerspaces could reduce this anxiety and lower the barrier to participation in making activities [9].

There is introductory research that makerspace community participation and machine usage can lead to stronger design self-efficacy, developing and fostering an inclusive and diverse environment is important to help overcome initial anxiety [8]. This can be done by hosting events, workshops, and new groups that might not otherwise be held in a makerspace. Communication and publicity also play a part in spreading information to a new, more diverse audience [9]. Because these spaces often foster or highlight students who are already comfortable in engineering environments, inclusion of new or underrepresented users has been encouraged by creative workshops and social events [1].

Methods

The academic makerspace described in this paper was opened in fall of 2016 at the New York University Tandon School of Engineering. It is open to all students, staff, and faculty in the university. Following the classification system described by Wilczynski and Hoover (2017), the makerspace is designated:

- S-1: Grassroots and initial efforts (scope)
- A-4: Access provided to the entire University community (accessibility)
- U-4: greater than 3,000 members (users)
- F-3: 5,000-20,000 square feet (footprint)
- M-3: Faculty/Professionally managed with a hybrid (professional and students) staff (management and staffing)

Where the ‘S-1’ designation is assigned to any space less than two years old and refers to scope as “S-1: Grassroots and initial efforts, S-2: Programs that significantly support at least one university mission, S-3: Programs that significantly support three university missions” [10].

The makerspace is run by a manager and assistant manager. It is staffed with a group of 26 teaching assistants, composed of 22 undergraduates and 4 graduates. Two of the graduate students work as Greenhouse guardians (the Greenhouse is the programming arm of the makerspace) and their role is to coordinate and market workshops, as well as be facilitators for new users and come up with ideas for new workshops and events and reach out to students, student clubs, and experts (within the faculty and outside of the university). They work in close relationship with the makerspace manager and a faculty member who acts as faculty advisor to the Greenhouse program.

Based on the learnings of the first year of this programming, several design interventions were put in place in order to increase students’ engagement and learning through the programming. Three types of workshops were created: technical workshops led by the TAs working in the space, a design thinking (called “Ideation and Prototyping”) series, and a series on food and

sustainability. These workshops were organized and coordinated by the guardians but the content was created and facilitated by different actors: TAs, faculty and industry experts, student clubs, and a student "champion" with a passion for food and sustainability. In spring 2017, TAs were invited to organize and facilitate workshops in the makerspace. This was then made mandatory as part of their TA position and formalized in their offer letter. Student clubs and experts (faculty or from the industry) were invited by the guardians to create and facilitate workshops on specific methods and topics. During the fall, based on previous research, it was decided to identify a topic of interest for students (as community of practices usually emerge around specific topics of interest) and potential student champions.

Peer Led Teaching – TA Workshops

Based on student interest for specific "maker" and prototyping skills, all TAs were required to create and lead at least one workshop per semester. If more than one TA was interested in a topic or range of topics, creating a series of workshops together was encouraged. TAs would pick a topic, create a short Google Sheets presentation in the shared Drive and plan or request any needed materials. The presentation typically included some brief background info, for example resistor color codes, simple circuits, and Arduino examples for an Arduino workshop. The goal of each workshop was to provide a hands-on or interactive activity for all participants.

Occasionally, TAs would work with an outside organization; Major League Hacking (MLH) sponsored the workshop on Amazon Alexa and provided the presentation and workshop content, which was then led by the TAs with help from MLH. Two of the series workshops also involved faculty members: the ideation series (described below) and the Halloween series. The first Halloween series workshop was run by faculty member interested in cosplay. He had several years of experience creating foam armor pieces and had many examples and templates to share. Several makerspace TAs who were also interested in cosplay and more creative maker projects assisted the faculty member with that workshop.

Design Thinking – Ideation and Prototyping Series

The Ideation and Prototyping series aimed to better prepare students for design projects and competitions in the following semesters. In particular, based on the observations of the faculty advisor (overseeing a prototyping fund program) and inputs from organizers of various competitions within the university, it was noted that many students struggled to come up with initial ideas as well as to articulate them. Hence, in the fall semester, workshops' topics were ideation, sketching and rapid prototyping and focused on how to use those tools to explain, elaborate, and support initial ideas. For example, the sketching workshop started with basic practice of straight lines and boxes, then introduced perspective and surfaces. At the end, the attendees were then asked to sketch a simple soap dispenser. The first workshop was led by a local industry expert, the second was led by a graduate student with an industrial design background, and the third was led by an adjunct faculty member who also works full-time as an industrial designer. Spring semester workshops will include a general introduction to design thinking, rapid prototyping as well as more specific prototyping tools. Workshop topics and order are shown in Table 1.

Table 1: Ideation and Prototyping Workshops

Fall Semester	Spring Semester
1. **Ideation Framework** 2. **Visualizing with Design Sketching** 3. **Thinking with Prototypes**	1. **Introduction to Design Thinking** 2. **Rapid Prototyping** 3. **UX Prototyping Tools** 4. **Data Visualization with 3D**

Emerging Technology and Special Topics –

Food and Sustainability Series

Previous research of the makerspace suggested the need to create community of interests in order to nurture the emergence of a community of practice. Following a community of practice's approach, one graduate student who was particularly engaged and had been working on a vertical farming installation in the space for over a year was invited to create a series with around those topics. He proposed topics and industry guests to invite, usually reaching out to those guests himself, and the guardians helped with promotion, event hosting, and logistics. The goal was to create a community of interest that would lead students to be inspired to start their own projects in the field and to connect them to local professionals and opportunities.

Student Club Events

Student clubs were also encouraged to organize public workshops around various themes of interest. In particular, one student club, Design for America, was very engaged in creating opportunities for other students to learn design thinking and how to use it to tackle social challenges. They often partnered with other design thinking local meetups, such as OpenIDEO. In the fall 2017 semester, the club organized two panels with industry experts on strategic and community-centered design. Both events were well attended, with approximately 45 attendants.

The same club also organized two workshops to support specific student design projects. The first was open to university affiliates only, by invitation, and brought 15 students, a faculty advisor, and the manager of the makerspace together to help a first-year student scope a project. The student had started to analyze water management for rice farmers in the Northern Philippines. The second workshop was a refinement pop up organized with a local meetup organization to provide design feedback for several prototypes created by a non-student team who had developed a first iteration of an artificial intelligence system for caregivers of patients with dementia.

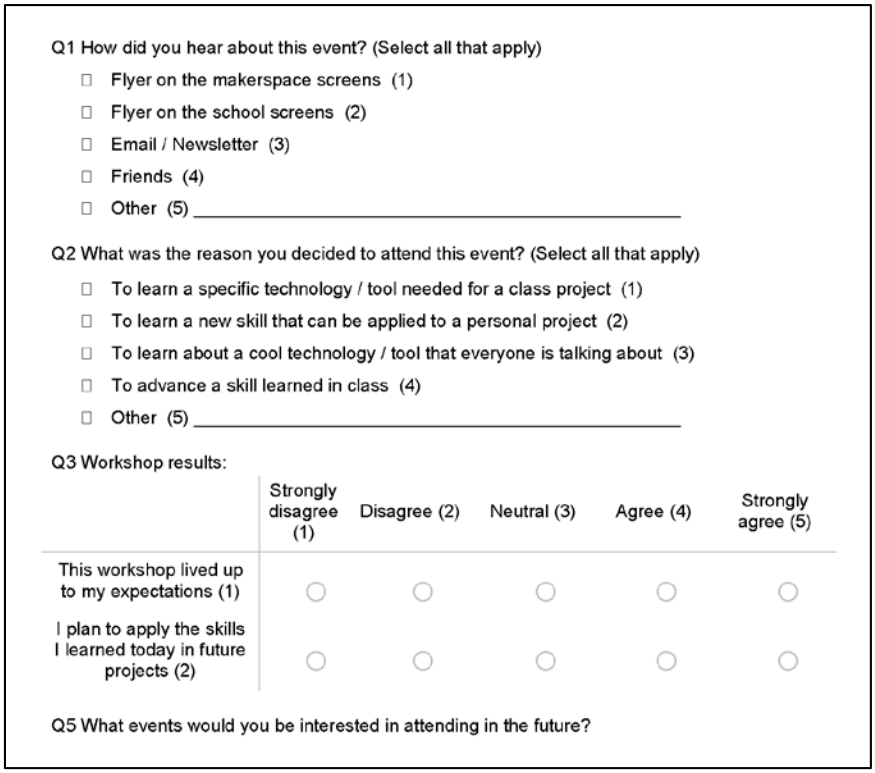
Another student club, focused around prototyping and innovation, worked with a faculty member and a Hololens technology local meetup to host monthly hack nights. The faculty member had created an augmented reality (AR) project based course which meets in the makerspace and uses the Hololens. The events organized by these two student clubs suggest the importance of

encouraging these efforts to create connections within and outside of the university and to nurture a sense of community.

Data Collection

Workshops and makerspace data were collected in three different ways. First, the university internal student events portal contained all student ID card information and allowed events to be logged with a cheap magnetic card swipe connected via USB to a laptop. In addition, a short survey was created for workshop attendees and shown in Figure 1, below. Third, a ten question survey was developed previously to send out to students who use the space at the end of each semester. This general survey was updated to better ask about possible makerspace improvements, including workshop improvements or topic requests.

Qualitative observations and interviews were performed by two graduate students who worked as research assistants in the space for 15 hours per week. Two graduate students with design research skills worked with a faculty member to collect qualitative data from September to November 2017. These data consisted of over 35 sessions of in-person observations and 20 sessions of long and short interviews. These data were analyzed by the two students and faculty in bi-monthly sessions and led to the creation of the Ideation Series and the Food and Sustainability Series. One of the graduate students continued working throughout the spring semester (January – March 2018) and conducted interviews with the TAs.



Q1 How did you hear about this event? (Select all that apply)

- ☐ Flyer on the makerspace screens (1)
- ☐ Flyer on the school screens (2)
- ☐ Email / Newsletter (3)
- ☐ Friends (4)
- ☐ Other (5) _____

Q2 What was the reason you decided to attend this event? (Select all that apply)

- ☐ To learn a specific technology / tool needed for a class project (1)
- ☐ To learn a new skill that can be applied to a personal project (2)
- ☐ To learn about a cool technology / tool that everyone is talking about (3)
- ☐ To advance a skill learned in class (4)
- ☐ Other (5) _____

Q3 Workshop results:

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
This workshop lived up to my expectations (1)	○	○	○	○	○
I plan to apply the skills I learned today in future projects (2)	○	○	○	○	○

Q5 What events would you be interested in attending in the future?

Figure 1: Workshop Survey

Results

All makerspace led workshops for the fall 2017 semester are shown in Table 2 with number of university affiliated attendants. Some were open to the public and had higher total attendance, but public numbers were recorded separately. Workshops which focused on new, emerging technologies had the highest attendance: Alexa Voice API Programming (22), Intro to Machine Learning (25). Because workshop attendance can now be easily tracked by swiping school ID cards, it was possible to track return attendance. There were 22 students who attended two workshops over the fall semester, and ten students who attended three or more workshops. Six of those attended multiple workshops that were part of a series (Solidworks, Halloween DIY, Ideation Series). Of the remaining, three students attended multiple workshops that were offered in the same day or two, and the remaining student was deemed a motivated outlier.

Table 2: Fall 2017 Workshops

Workshop Title	# Participants
Prototyping Fund Info Session	13
Coding is Fun: Decoding Alexa	22
Halloween DIY #1: Foam Armor	8
Intro to Solidworks (2)	17
Intro to Raspberry Pi	17
Halloween DIY #2: Decorations	8
Intro to Electronics	10
Intro to Arduino	14
Advanced Solidworks (2)	8
News from the Oculus Connect Conference	15
Halloween DIY #3: Witch/Wizard	12
Urban Food Lab	18
Intro to Fusion360 and Othermill	8
Intro to Machine Learning	25
Carbon Fiber Laminate	8
Laser Cutting 3D Sculptures	10
Intro to Game Development: Board Games	4
Ideation #1: Ideation Framework	16
Vinyl Stickers	10
Ideation #2: Visualizing with Design Sketching	13
Fusion360	5
Ideation #3: Thinking with Prototypes	11
Urban Food Lab: DIY Mushroom Grow Kit	11
Holiday Gifts	11
Hand Tool Safety	3
Total makerspace workshop student participation	**297**

Workshop Survey Results

Workshop attendee survey response was very low: n = 6. For fall, the survey was developed during the first two months of the semester and then sent out to students in an email after they attended (for workshops in the final months). To combat low response, the survey will be available in paper format at the end of each workshop and via a QR code link for spring semester.

Most indicated that they learned about the workshop through email or newsletter. All respondents indicated that they had chosen to attend **to learn a new skill that could be applied to a personal project**, with one also selecting they attended **to learn a specific technology/tool needed for a class project** and one **to network with others**. Topics of interest for future workshops were: **coding (2), graphic design, virtual reality, microprocessors, 3D printing, and more urban farming focused workshops**.

General Survey and Student Interest

A survey was sent out to all students who had entered the space in the Fall 2017 semester to assess student motivation for using the space, desired improvements or changes, and workshop topics of interest. This is a developing instrument, attempting to get a longitudinal view of the uses and perception of the space. As the extracurricular and curricular use of the makerspace increases and the workshops are formalized, a new survey will be created in the future to better understand student design skills and design self-efficacy by introducing elements from Carberry and colleagues' instrument [11].

Academic year of the respondents (n=126) is shown in Figure 2, and 39% of the respondents identified as female, 56% identified as male, and the remaining 5% selected other or prefer not to say. The majority (44%) of students selected that they come to the makerspace once a week or less, with 30% selected 2-3 times per week, 16% 4-5 times per week, and 10% selecting more than 5 times per week.

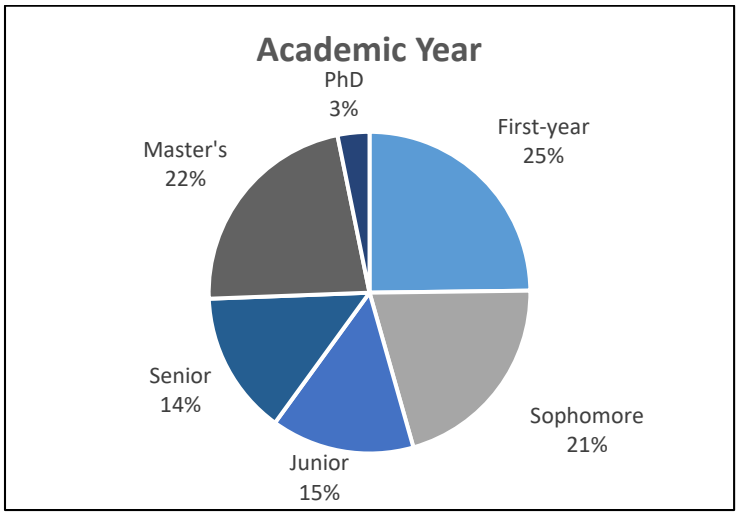


Figure 2: Survey Demographics

Figure 3 displays the response to the Likert style questions on students' perception of space use. The statements were framed to investigate how students perceive use of the space and machines in their design process. Receiving feedback and funding and participating in the community received more neutral or negative responses.

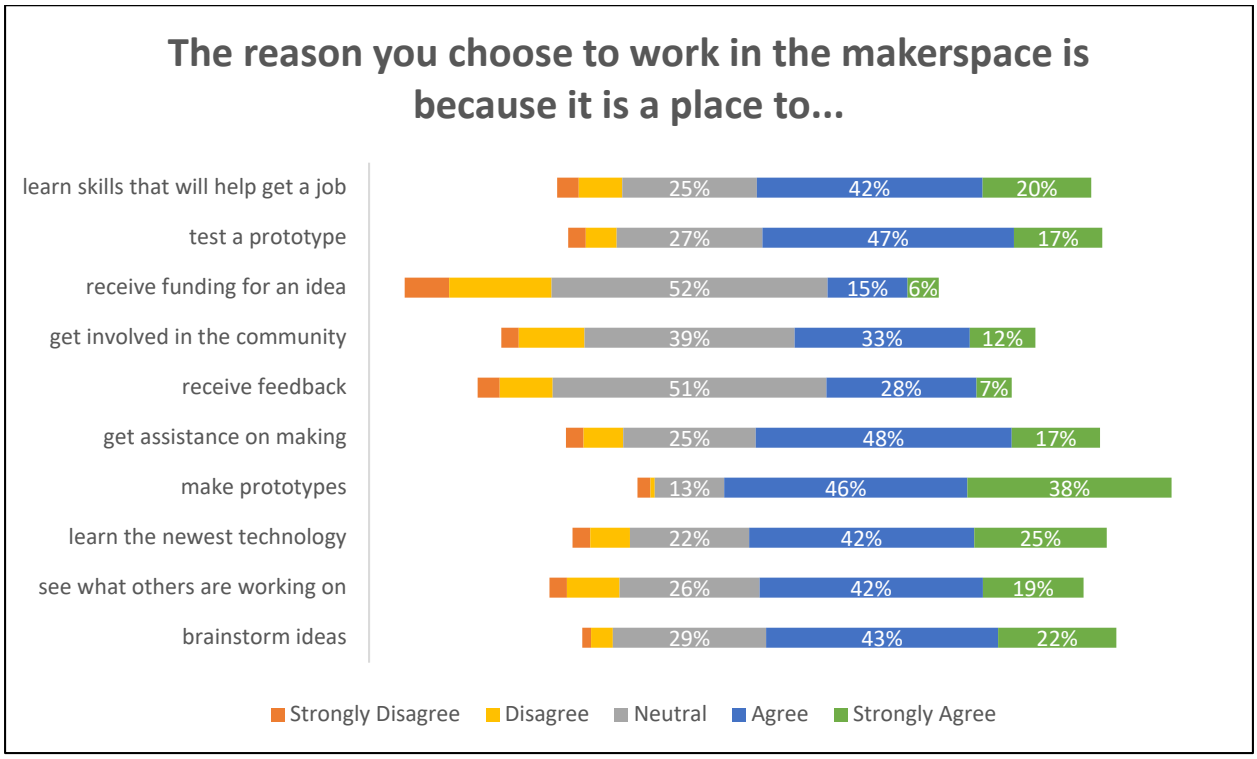


Figure 3: Survey Response, Makerspace Usage

Figure 4 displays the selection options and responses for space improvements. Of the provided options, the most popular were:

- List of available tools in the space
- Past projects that illustrate how they were made
- Design files provided for common shapes or projects

There were also several possible short entry responses on the survey for student recommendations: possible new training sessions, new workshops, and other, open-ended suggestions. Respondents wanted to see more workshops covering **CAD software, soldering, making clothes with the sewing machine, more Arduino, more mechanical analyses software, and more "design work" workshops**. Students also requested more workshops at different days and times.

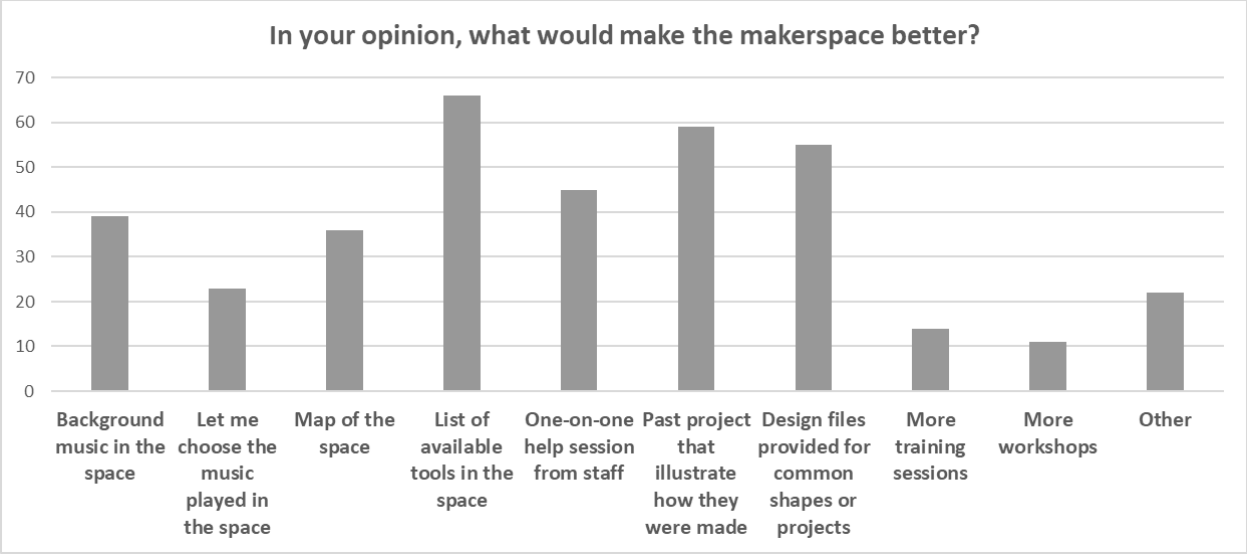


Figure 4: Survey Space Improvements

Qualitative Observations –

Workshop Attendance and Reception

Anecdotal evidence from the ideation framework and prototyping workshops in the fall suggested the perceived value of the workshops by students: students were positive about their learning experiences and said it helped them think about their class and personal projects in a different way. The workshop provided them with opportunities to develop design skills they did not have the opportunity to learn in a classroom environment. In the spring, participants of the first workshop of the Ideation series (an introduction to design thinking) expressed a similar perceived value. Several participants asked about the next workshops times and dates suggesting that they interpreted the "series" label as signaling a structured offering that they wanted to benefit from.

The Food and Sustainability series had two events in the fall semester with two more planned for spring. The first workshop served as a networking event, with a local co-working space (focused on vertical farming) manager presenting information about the industry and opportunities. The second fall workshop in this series was more hands-on: attendees created a mushroom planter that they were able to take home. The third workshop, in the beginning of spring, was a cooking lab using seasonal fresh ingredients from a local farm. These events were well attended and confirmed a growing interest among students for issues around food and sustainability. The attendance in this series was across schools in the university and brought in the most participants from outside the university (additional to the numbers in Table 2). Students who participated had the opportunity to meet with professionals in the area and to increase their network. Industry professionals who attended had the chance to learn about the makerspace and meet with students.

Based on the success of the Food and Sustainability Series, other themes were explored. In the fall, the guardians tried to create a second theme series around AR/VR but it was found that students had interests for different fields of application, and in some cases students were simply

interested by the technology. No community nor student champion emerged. This spring, the two guardians – based on their own interest and some informal interviews with students in the makerspace – are exploring the possibility of develop a series on biomimicry. It is currently being developed by reaching out to local industry experts and faculty.

It was found that the labeling as a “series” worked as a signaling mechanism that helped engage students. Observations from fall 2016 and spring 2017, as well as feedback from the technical workshops, indicated that most students were not aware of other workshops and they often did not recognize the connection between workshops. The “series” label helped creating a sense of continuity.

Student Creation and Facilitation of Workshops

Interviews with TAs suggested that they felt that leading a workshop was part of their job. However, some of them saw it mostly "as a job" rather than as sharing knowledge and engaging others. When TAs were more passionate about the workshop subject matter, there was a higher engagement of participants. Moreover, some workshops were too focused on a specific technology without highlighting or teaching connections to what students could build or how to apply the skills learned (that is, connecting to the design process). During interviews, four TAs mentioned that they should be more service-oriented. They personally enjoyed the service aspect of the position but recognized that it was not the case for all TAs and that as a group those skills needed to improve. Two of them expressed interest in helping developing a facilitator guide to help other TAs become more service-oriented. These TAs expressed their interest in building a community in the makerspace and helping other students learn new skills and/or develop their projects.

The student championing the Food and Sustainability Series has been extremely pro-active and autonomous. He was offered space, resources, and support for marketing and organization through the guardians, and he has led and facilitated speakers and topics for the workshops. He also brought in additional students to support his work and the series. This case confirmed the importance of passion and intrinsic motivation for generating communities of interest. Both student clubs that led workshops or events in the space were actively involved in connecting with community outside of the university. A large part of the DFA mission is to provide learning opportunities to other students, which stimulates excitement to use and lead workshops in the makerspace.

The role of the two guardians has evolved over the past two years. In fall 2016, the guardians were mostly expecting student clubs to reach out to them and did minimum outreach effort. This led to a redefinition of the position with a focus on creation of content for the programming. However, during the fall 2017 semester, the two guardians took it as mostly a coordinating job. So, during the spring semester, the need to think strategically and make connections was emphasized to the two new guardians. For all of the student facilitators, it was clear that a sense of self-efficacy and autonomy were important in the success of the workshop. Intrinsic motivation and personal interest in the subject matter, rather than focusing on the workshop as a job, were also important. This supports the findings by Gerber et al emphasizing social

persuasion, vicarious learning, and mastery experiences to successfully create extracurricular design-based learning experiences [2].

Over the last two semesters, experimentation with peer-to-peer teaching (creation and facilitation) at the makerspace suggests that it can be successful outside of the classroom but requires extra support because of the lack of boundaries. Peer teaching in the typical classroom environment clearly institutes a time and attention structure and also usually provides clear learning outcome goals - students are assigned a topic to teach in a single session or a few sessions [10]. In an extracurricular environment, staff and faculty should provide feedback on the topics chosen and check in during the workshop creation process to guide and boost the interactive portion of the workshop, especially for younger student teachers or highly technical workshops. Indeed, it was found that mentoring was important to the success of the different programs: the two student clubs have very active faculty advisors, the makerspace manager interacts on a daily basis with the TAs and has created more structure to support the development of social skills.

Discussion and Future Work

Research on academic makerspaces tends to focus on curricular activities and projects in the space. This paper shows that on top of curricular activities, makerspaces can provide students with extracurricular resources to develop design engineering skills and a design thinking mindset. However, for the space to play this role, it needs to provide more than access to machines and even more than just technical workshops. Based on previous research on interactions and use of the makerspace and in line with a peer-to-peer philosophy, several types of workshops were explored. Each type was originally conceived as a single design intervention. For example, the technical workshops aimed to encourage students to use machines by providing them with more expert skills. As TAs collectively had skills on all the machines, it was decided to ask them to offer these workshops in order to increase their interactions with students in the space. As for the ideation series, it emerged from the realization that students needed more process skills in order to use their technical skills in a meaningful way. The findings from these last two semesters have shown the values of these different workshops but also suggested the need to take a more systemic approach both in conceiving and communicating the offering to students. Hence, a “Prototyping School” series of workshops (aiming at developing both process and technical skills) has been proposed and will be piloted in fall 2018.

While peer-to-peer learning needs to be structured and “invited” (in some cases, required), it can increase the sense of community in the space as core users are invited to encourage increased involvement from peripheral users and made accountable for the community within the space. From previous research of communities of practice [13], having several champions to nurture these communities is very important and was supported by these findings. Having a graduate student who was very involved and already actively seeking out industry experts for the Food and Sustainability series helped bring in outsiders and build a community around that theme.

Exploring new ways to nurture emerging communities of interest to create a broader makerspace community will be the focus of staff and faculty research.

Many academic makerspaces offer design consulting and project feedback, specifically for capstone design projects and entrepreneurial projects [12]. Future training and development for TAs will focus on cultivating and mentoring specific technical skills so that TAs can provide more technical design feedback and teaching. Many student design teams – Hyperloop, Self-driving Car, Baja SAE, Concrete Canoe, Steel Bridge – already independently use the machines and hold team design meetings in the makerspace. These teams employ collective learning, which can increase design self-efficacy, as they form their own small communities [2]. To assess design self-efficacy, a modified version of the instrument created by Carberry et al will be developed in the future [11].

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