Creating a Makerspace for Cross-disciplinary Teaching and Collaboration with Limited Funding

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Creating cross-disciplinary programs at post-secondary educational institutions is challenging. Faculty and student schedules are full of teaching, research, service, and learning requirements that are on relatively strict timelines. In an effort to overcome these challenges, an ad hoc team was formed at California State University, Chico with representatives from all seven colleges. Three main pillars of innovation were identified (1) an entrepreneurial learning experience, (2) an on-campus makerspace, and (3) community outreach and engagement. This paper focuses on the design, implementation, and success of the on-campus makerspace and as well as the lessons learned and areas for improvement. The space is entering its third year of operations and has seen over 1,500 projects completed in spring 2019, a marked increase in usage.

Introduction

The maker movement is empowering everyone to explore creativity and learn new skills and concepts through building and making. When brought into an academic setting, the maker movement looks like applied educational constructivism [1] and [2]. Students, faculty and staff, with expert guidance and support, are embarking on their own educational journey motivated intrinsically by their sense of curiosity, wonder, and desire to accomplish and create.

Adopting makerspaces in higher education can have direct and clear benefits for faculty, staff, and students [3], [4], [5], and [6]. Faculty can provide content and context in the classroom and then create assignments for students to complete in a makerspace where they might construct artifacts, create drawings, digitize objects, make models, etc. The possibilities have few limits when individuals are empowered to be creative and new technologies continue to become available and accessible. Students can not only complete assignments but also learn something new or design and build a project for their personal use or campus club. Providing unique opportunities for staff to explore their own creativity can provide a positive working environment and potentially provide staff with additional capabilities that they can bring back to their work thereby enhancing their own skills and contributions. A makerspace can positively impact a large majority of the campus community.

The vision for a new makerspace began to take shape as a direct result of an initiative called the Bridge Entrepreneurship Program, which was started by an ad-hoc committee to provide the organizational framework for building resources and infrastructure to promote entrepreneurial endeavors on campus and in the community. Co-chaired by the authors, the committee engaged with campus and the regional business community to devise an action plan. The three pillars of the plan included a faculty entrepreneurial learning experience, developing a makerspace, and enhancing outreach to the public and private business community. The focus of this paper is on how the makerspace was developed, challenges that were faced and overcome, initial results, lessons learned, and future direction.

Makerspace Development

The overarching goal for the makerspace was to create and foster a culture of entrepreneurship and innovation across campus in both research and teaching and support the campus culture of applied and hands-on learning in all disciplines. It was important that the space have capabilities for making physical objects, i.e. prototyping, and not just digital artifacts, renderings, or programming.

Stakeholders were identified from the authors' broad network of contacts and included faculty, staff, administrators, private businesses, and public services representatives. The authors visited local businesses and governmental offices, for example the Chamber of Commerce, Economic Development Offices, and county workforce development programs, to communicate and share the vision of the Bridge Entrepreneurship Program, create stronger ties to the university, generate support for the makerspace, and gather input. This took place over approximately six months.

Additionally, several nationally recognized university libraries and makerspaces were identified and contacted [7, 8, 9]. Phone interviews were conducted and many questions were asked. All the information was collected and shared with the Bridge group for discussion and decision making.

After meetings and data gathering, the vision of the Bridge Entrepreneurship Program was shared with all stakeholders at a kick-off meeting. The audience was also given an opportunity to share their experiences working with the California State University, Chico (CSU, Chico) and provide feedback and input on what the future might look like working together. In attendance were faculty as well as community members from the county office of education, economic development agencies, representatives from several neighboring towns and school districts, consultants, workforce development agencies, and a local fabrication lab. A mailing list of over 77 stakeholders representing 22 different public or private organizations was managed and input was sought from everyone throughout the planning and development process. Meetings were held quarterly and initially focused on collecting input from stakeholders on all three pillars of the Bridge program.

The following main goals of the makerspace were established. These goals drove many of the decisions that were made and supported much of the outreach and early development of the space.

- Be available to all students, faculty, and staff of any major, department, or office.
- Out-of-pocket costs to the user would be minimized.
- Equipment would include the ability to make physical artifacts.
- Students would operate and assist in the management of the space.
- Provide a place for team meetings and group projects.
- Provide support to users but not be a service provider.
- Do not compete with local for-profit fab labs or 3D printing clubs.

Location

As the Bridge Entrepreneurship Program became more widely recognized across campus, the Dean of the Library offered to locate the makerspace in the library. Initially, the desire was to locate the space where airborne particulates, smoke, and fumes could be vented. However, due to the high cost of retrofitting the library's infrastructure in order to install a ventilation system, it was decided that only equipment that did not emit dust or smoke would be used in the makerspace.

CSU, Chico is a residential campus with about 17,000 mostly undergraduate students in almost 300 different majors from engineering to English, sociology to kinesiology, art and hart history, and more. The library is prominently located near student services and student government buildings. This is an active area of campus where students congregate, meet, demonstrate, and present their clubs and activities to the greater student-body. Locating the makerspace in the library and near high student foot-traffic areas would help students to become aware of the new makerspace and feel like it was a part of their campus resources and not solely associated with a college or department. An early concern was the potential that locating the makerspace in a room in the college of engineering or other STEM college or department could give the impression that only STEM students could use the facilities and students from other majors might feel discouraged from using the space. The library location was widely accepted as the ideal location largely due to its inherent neutrality.

The library makerspace is located on the second floor of a four story building adjacent to the copy center and a group study area. At approximately 1,300 square feet, it is nestled in a corner of the library where one movable divider acts as one wall separating the makerspace from a group study area with the other two and a half sides being a permanent wall and the entrance to the space located along the other half wall. Figure 1 shows the second floor layout of the library with the location of the makerspace identified in red.

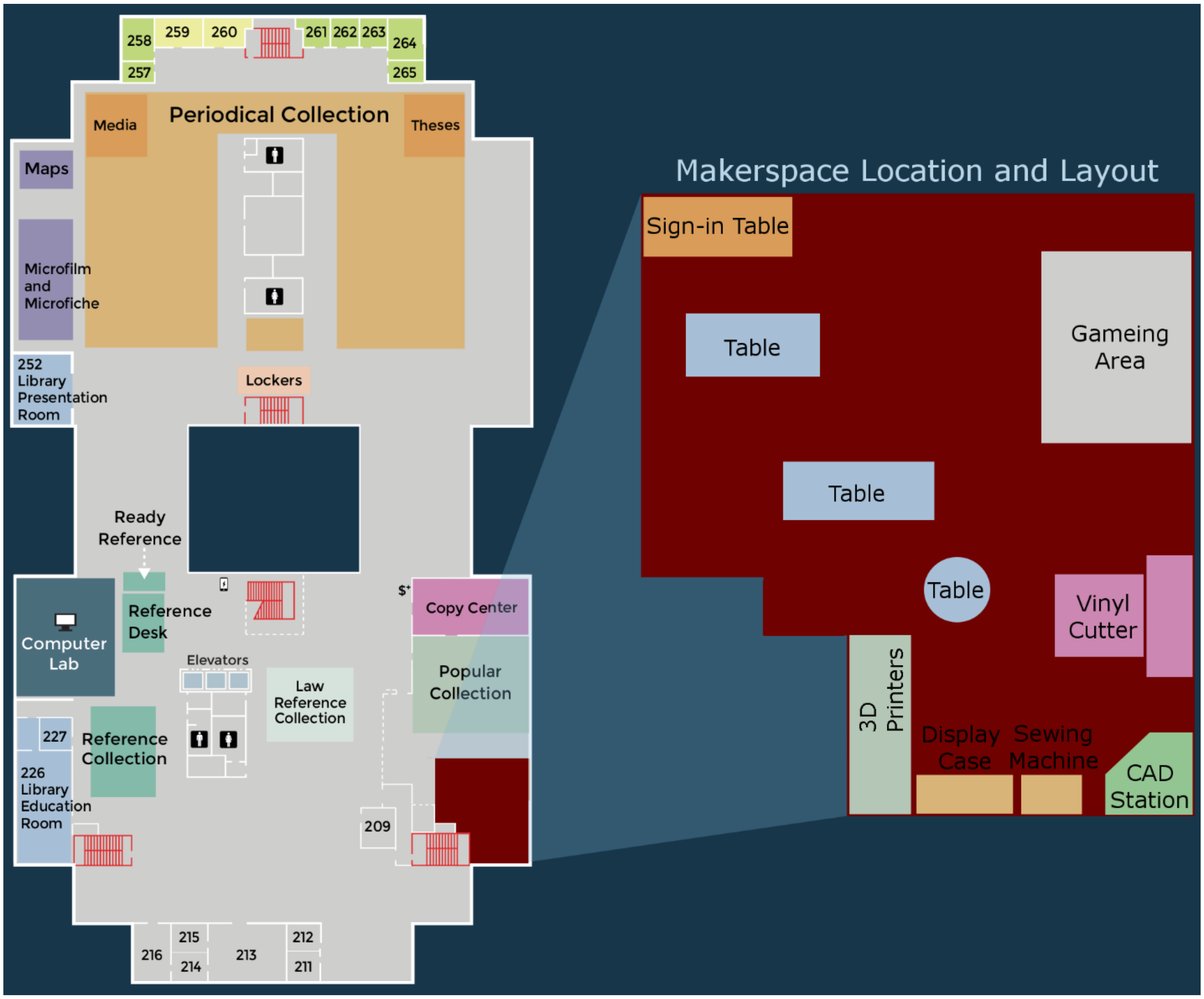

Figure 1. Library Second Floor Plan on the Left and Makerspace Location and Layout Enlarged on the Right.

Equipment

Approximately, fifty faculty from nineteen different departments, all seven colleges, deans and other administrators, and librarians were contacted and asked to provide input and ideas for how they would use a makerspace and what equipment would be important to have. Twenty-four faculty were interviewed by a graduate student. Faculty were asked what equipment they would want, how they would use it, in which classes it would be used, and other suggestions for the space. A list of the equipment identified and frequency of times it was suggested is shown in Table 1. The most frequently requested equipment was software, Adobe Creative Cloud, followed closely by 3D printers. Many other types of equipment were identified but by only one or two people.

Table 1. Faculty suggestions for desired equipment and frequency of each suggestion.

Equipment Suggestions	Frequency
Adobe Creative Cloud	17
3D Printer	16
Laser Cutter	5
Wacom Interactive Pen Display	5
Sewing Machine	5
3D Capturing Tools	2
iOS and Android Devices	2
Lights for Photography	2
Electronic Tools	2
Server (for hacking)	2
Vacuum Former, Color Printers, Photography Tools, Carpentry Tools, Arduino, Rotary Tool Kit, Basic Circuit Components, Routers, Vinyl Cutter, Xbox1, Commercial Kitchen, Screen Printing	1 response each

After extensive discussions and research [3, 4, 5, 6, 7, 8, 9], the committee opted for the list of equipment shown in Table 2. Some of the equipment is available to all users of the space while other equipment is used only by the student employees, called Makerspace Student Advisors. All the equipment that is available for use requires some degree of training and a signed liability waiver.

Table 2. Equipment currently offered for use either directly by users or only by makerspace student advisors.

Equipment/Software	Training Required	Material Cost
Roland Camm Vinyl Cutter	Drop-in	$5.00 per yard
Juki Industrial Sewing Machine	By Appointment	User Provided
Wacom Cintiq 13HD Creative Pen Display	Drop-in	No Charge
Button Maker	Drop-in	$2.00 per 10 buttons
Cutting Board and Cutting Tools	Drop-in	No Charge
Epson Perfection V800 Photo Flatbed Scanner	Drop-in	No Charge
Einscan-S 3D Scanner	Drop-in	No Charge
Ultimaker 3 3D printers (Extended)	Operated by Makerspace Student Advisors Only	3 hours per user per month, No Charge
3D Printer Pen*	By Appointment	Charged by filament length
Solidworks	Online Computer Reservation and By Appointment	No Charge

Adobe Creative Cloud	Online Computer Reservation and By Appointment	No Charge
Mac and PCs	By Appointment	No Charge

* 3D Printer Pen is a new device as of late spring 2019.

Management

Another goal of the space was to be partially or wholly managed by students and provide students with direct work experience. Students would be brought in early in the development of the space and wherever practicable take the lead in implementing initiatives and ideas for managing and operating the space. Initially, a faculty director (lead author) provided all the management, guidance, and oversight for the development of the makerspace. As much as was practicable and feasible students were empowered to engage in all aspects of running and managing the makerspace. They contributed in the development and creation of the project work flow, a user database, material and supplies re-ordering, equipment maintenance, user training, marketing and logo creation, and safety guidelines and procedures.

The creation of the makerspace started in the fall semester 2017 with one faculty member managing all aspects of interviewing, hiring, and training. Sixteen students from eight different majors including mechanical, mechatronic, electrical, and civil engineering, physics, media arts, art, and business information systems were hired. Initially, the makerspace was not officially open but makerspace student advisors covered shifts spanning approximately 10 to 12 hours per day during the week and 9 hours each on the weekend. Students set up the makerspace as well as worked with select classes and faculty on student projects as all processes were being developed.

A library makerspace manager was hired and with all makerspace student advisors, the one faculty member, other library staff, and campus environmental health and safety the following processes and procedures were created. See Table 3.

Table 3. Process and procedures created to manage the makerspace.

Process/ Procedure	**Artifact**	**Action**
Safety Agreement	Document	Read, signed by user, kept on file
Makerspace Rules and Policies	Document/ Online	Given to each user
3D Printer Safety Procedures	Document/ Online	Provided as needed
Sewing Machine Safety	Document/ Online	Provided as needed
Vinyl Cutter Safety Procedures	Document/ Online	Provided as needed
Solidworks Training	Online sources*	Links provided on website
Sketch Up	Online sources*	Links provided on website
Cura 3D	Online sources*	Links provided on website

Equipment Maintenance Schedule	Binder	Staff managed per schedule
Equipment Inventory List	Binder	Staff managed, re-order as needed
Supply Inventory List	Binder	Staff managed, re-order per schedule
User Intake	Database	User sign in, staff managed

* Sources available in public domain or Lynda.com and not developed at CSU, Chico.

Notable processes and procedures include the safety agreement, equipment safety procedures, and project workflow. The safety agreement was largely adapted from similar agreements found online including from the Hill Makerspace at the D. H. Hill Jr. Library at North Carolina State University. When a new user comes into the makerspace they are given a brief orientation and asked to read and sign the safety agreement. The safety agreement is filed and kept on-site.

All equipment was reviewed and researched for proper operating procedures. Manufacturer's manuals were adapted and the office of environmental health and safety was consulted and reviewed all equipment safety procedures and provided input and guidance on proper language, graphics, and warnings. These safety documents are reviewed each time anyone uses the equipment and copies are provided as needed.

The process of managing project work flow was developed over a period of months while students learned and developed their understanding about the work flow. Initially, there were considerable issues and problems with printing 3D objects. A user would get help from a makerspace student advisor and submit a project for 3D printing. 3D printing can be temperamental, sometimes a print job would fail. When the user came in to discuss the issue, they would often work with a different makerspace student advisor than the one that helped them originally. Communication between makerspace student advisor and the user was not captured adequately. At times users were getting conflicting suggestions or information. Within a couple of months of operating, it was clear that there needed to be a way to track progress and communication throughout the life of a project. An MS Access database was developed and a 3D printer project work flow sheet. The database records user print status including, student ID, email, print underway, nozzle size, extruder number, filament color, whether user was contacted, hours consumed, USB color and print status.

Each user with a valid university ID (faculty, staff or student) is allowed to print for a total of 3 hours per month. Users are allowed to pool their hours to print larger jobs. Projects are loaded onto a USB stick and placed in a queue for printing. Each USB has a unique color. This way any modifications to the 3D slicer software model is saved in one location. All original 3D slicer software models are generated by the user and after being reviewed by a makerspace student advisor, are saved to the USB drive. Only makerspace student advisors are authorized to run and manage print jobs. The 3D print project work flow sheet is generated for each print job. It consists of a physical piece of paper for documenting any issues or special notes about the print job. This project sheet follows the USB stick and printed part throughout production the development life-cycle.

The database also tracks users by major, class standing, project origination, and several other demographics as well as projects on other equipment in the makerspace and usage logs. The database has been tracking all users of the space and their activities since fall 2018.

Budget

There was no allocated budget for the makerspace when the idea was conceived. Funds to start the makerspace came from two main sources student fees and the library administration. The library committed $35,000 to purchase four 3D printers, 5 rolls of filament, one vinyl cutter including vinyl, 3D scanner, industrial sewing machine with servo motor, 27” Mac 3.3 GHz - 2TB computer, flatbed scanner, and digital pen and display. Additionally, the library purchased two industrial rolling tool carts with lockable drawers, cutting pads, many and various tools for sewing, 3D printing, and general craft making including scissors, pliers, cutters, x-acto knifes, tape, glue, string, rollers, button making materials and more.

Students were hired and paid through a student learning fee proposal written and funded for $31,000. These funds paid the sixteen makerspace student advisors working approximately 75 hours weekly for two sixteen-week semesters. These funds were from a pool of money available to faculty and students through a competitive proposal submission process. The proposal was funded the first year of operations. In subsequent years of operation, the library adjusted its budget to accommodate the increased labor wages for staffing the makerspace.

It is worth noting that the furniture in the makerspace which includes chairs, tables, desks, and shelving was all found in library surplus. The students found many matching pieces and created an inviting space for the campus community.

Figure 2. Makerspace Showing Layout and Furniture.

Makerspace Usage

From the beginning it was important to track users of the makerspace for continuous quality improvement and answer the following questions: who uses the space and why, what equipment is being used, how frequently do supplies need to be ordered, and where should marketing efforts be focused. The first year was a development year with fall 2017 seeing a soft opening in mid-November followed by a grand opening in February 2018. Many of the processes were modified over time for better effectiveness and efficiency. A database that tracks users was first designed in fall 2017 and then underwent significant modifications in fall 2018. As a result, the most comprehensive usage data includes fall 2018 and spring 2019. The parameters that were monitored the closest included frequency of use, which was measured in number of unique projects per time period, variety of student majors using the space, types of projects, and from whom the project was assigned.

The number of unique visits per time period was used mainly for managing resources and supplies. Overall, the total number of visits to the makerspace in fall 2018 and spring 2019, which is tracked by indicating the use of or participation in one of the following: 3D Printers, Vinyl Cutter, Sewing Machine, Button Maker, Computer Use, 3D Scanner, 2D Scanner, Wacom Tablet, Study Space, Movies/Games, Other?, and Tour, were 557 and 1585. A significant increase in activity occurred from fall 2018 to spring 2019.

The trend in using the makerspace can be seen in Figs 3 and 4. In general, the use begins low and increases throughout the semester with the notable exception of Thanksgiving break in the fall and spring break in the spring semesters. A week is measured from Monday to the following Monday with all activity of a given week displayed on that Monday in each figure. No activity is seen in the makerspace during finals week in either semester nor the week before Thanksgiving break in fall 2018 as seen in Fig. 3. The highest number of visits in any week was 151, which occurred the week of May 6th, the week before finals.

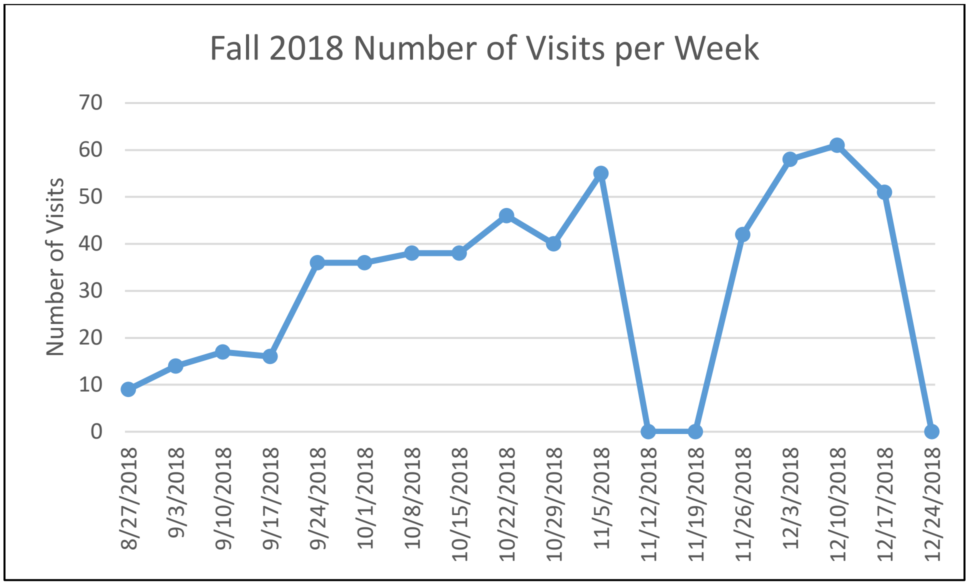

Figure 3. Weekly visits to the makerspace during the fall 2018 semester.

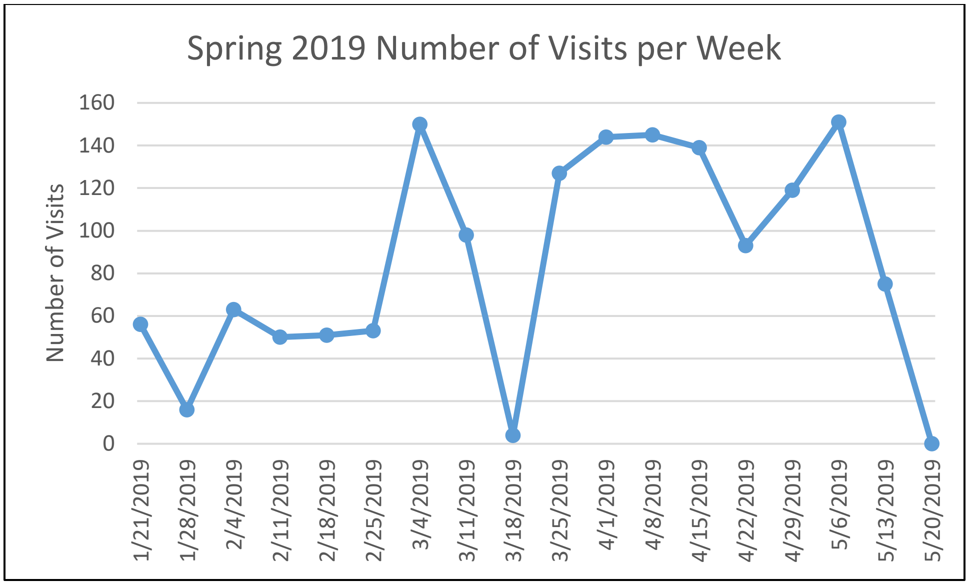

Figure 4. Weekly visits to the makerspace during the spring 2019 semester.

Interestingly, the most common activity in the makerspace is studying, which is then followed by 3D printing, vinyl cutting, and computer use. Studying saw over 500 visitors in spring 2019 and nearly 200 in fall 2018 while 3D printers were used almost 300 times in spring and more than 175 times in fall. Tools and 3D Pens activities were added to the database in spring 2019 and Other was removed, otherwise, the type of activities are the same in both semesters. See Fig. 5.

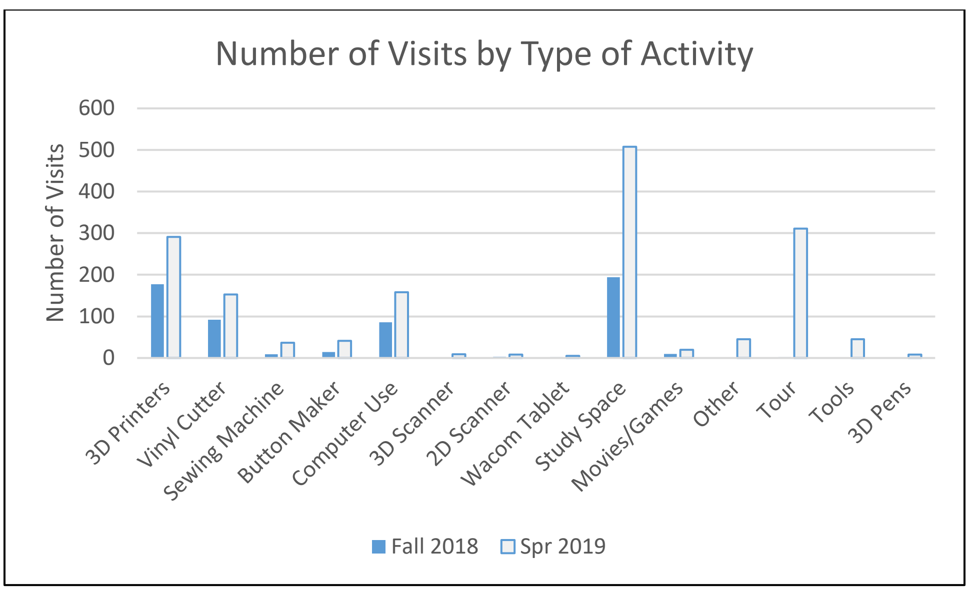

Figure 5. Number of visits by type of activity.

There were 60 different majors participating in activities in the makerspace in fall 2018 and 71 in spring 2019. Fall 2018 saw 85 unique mechanical engineering major visitors and spring 2019 the number dropped to 72. In both semesters, these were highest number of unique visitors to the makerspace of any other major on campus. Undeclared majors visited a total of 3 times.

Psychology majors visited 7 times and Liberal Studies majors visited 4 times. While STEM related majors visited most frequently there were several non-STEM majors that visited regularly, including Music and Political Science. Table 4 shows the top ten majors that visited the makerspace in both fall and spring semesters.

Of all 281 visits to the makerspace in fall 2018, 50% were categorized as a hobby, 40% were for a course, and clubs and departments accounted for 6% and 3%, respectively. Spring 2019 saw increases in hobby, club, and department usage of 53%, 15%, and 7% whereas course usage dropped to 24% out of the 328 unique visitors.

Table 4. Top ten majors that visited the makerspace in fall 2018 and spring 2019 and their frequency.

Major of Visitors Fall 2018	**#**	**Major of Visitors Spring 2019**	**#**
Mechanical Engineering	85	Mechanical Engineering	72
Mechatronic Engineering	18	Mechatronic Engineering	28
Civil Engineering	12	Civil Engineering	19
Biology	11	Not Specified	17
Business	9	Computer Science	13
Computer Information Systems	9	Psychology	12
Physics	8	Computer Animation	10
Computer Science	7	Business	9
Psychology	7	Biochemistry	9
Electrical Engineering	7	Communication	7

The frequency of visitors was also tracked based on the time of day that they entered the makerspace. Both fall and spring semesters shows a similar trend of usage with noon being the busiest time. In fall 2018, the hours of operation were from 11:00 AM until 10:00 PM. These hours were changed to 8:00 AM to 7:00 PM based on how few visitors came to the makerspace at night. In fall 2019, the hours were changed again to reflect the current hours of operation which are 10:00 AM to 5:30 PM. Figure 6 shows both fall 2018 and spring 2018 hours of operation and the number of visitors during each open hour.

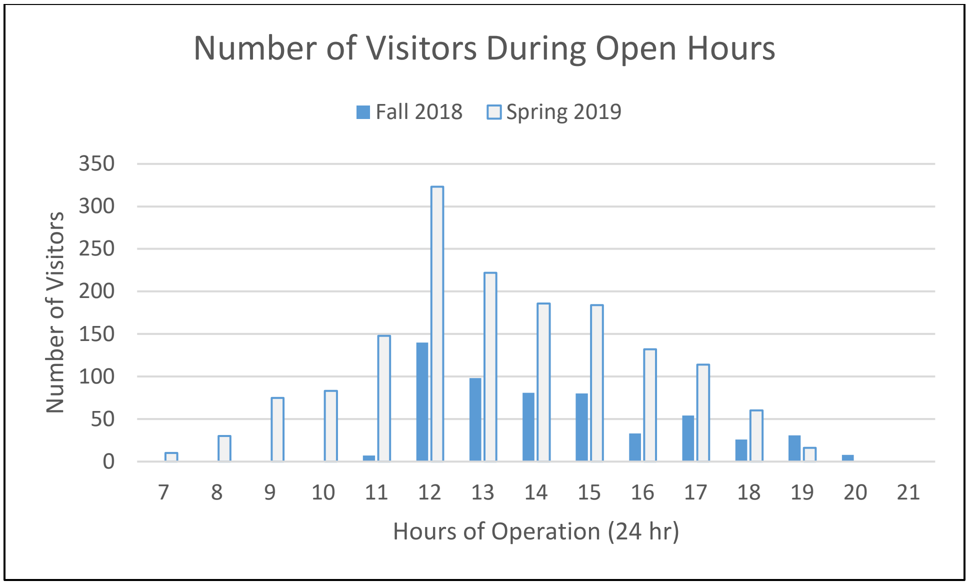

Figure 6. Number of visitors during each open hour of operation.

Training Students

Hiring and training all the Makerspace Student Advisors, while rewarding, was a significant time commitment. Sixteen students applied and sixteen students were hired. This process took approximately two months, one month to advertise the position and another month to review applicants, interview and hire. Once hired, the library administration took over the hiring process and ensured all students completed the proper paperwork as per human resources, which was a significant help. The library also managed the student's timesheets and submitted hours to payroll. This amounts to at least several hours per month dedicated to reviewing, correcting, approving, and submitting timesheets.

There were times when users did not get adequate service, mostly with regard to 3D printing. When a user had no experience with 3D printing, their expectation was generally that they would be able to get a plastic printed part within minutes and be exactly as they envisioned. And, the makerspace student advisors generally understood the process of making a 3D printed part as an iterative exercise, with multiple attempts necessary in order to make a satisfactory part. These two perspectives were often in conflict, as a result user expectations were not well managed in the early days of the makerspace.

At first, the makerspace student advisors were drawn into customer projects in such a way that they wound up doing the project for the customer. This is natural when first seeking help. However, one of the main goals of the makerspace was to empower others to be creative and learn new skills. As a result, there had to be a shift in the way the makerspace student advisors approached helping the users. There were many meetings where the topic of discussion was focused on how to encourage customers to take ownership of their own project and point them toward resources that would help. Key resources were posted to the library's makerspace page, which made it easy to show users where to find appropriate information. Also, the makerspace student advisors practiced active listening and empathy building in order to best understand what the users' needs were and to remain supportive without taking over the project. While it was not easy for the makerspace student advisors to shift from doing to overseeing, especially with so many engineering majors on staff, however over time they were much better at setting customer expectations and were more direct communicators. The mantra in the makerspace became, "We're a makerspace, not a make it for you space."

The sixteen makerspace student advisors were excellent. They were highly engaged, motivated, and a joy to work with. They took initiative on many aspects of creating the makerspace including fixing equipment, moving furniture, making signs, establishing a schedule, and greeting the customers and helping them to feel welcome. Their work and dedication to the space was invaluable. Certainly they were paid for their efforts, however they deserve so much credit for creating a successful and enjoyable space on campus.

On-Going Support

After the makerspace had been operating for three semesters, the library was uncertain of their budget due to potential funding cuts at the university. After careful review of the data, it was clear that users did not come in early and rarely stayed late. This made reducing the hours relatively easy without reducing the overall benefit of the space to the campus community. As seen in Fig. 6, the majority of projects took place during the hours of 11 AM and 5 PM. Also, a new position was created. It was an on-call makerspace student advisor position during the times that the makerspace would sometimes get busy. This student would call in and a decision was made on the spot based on activity in the space whether or not additional help was needed.

In the first year of operations, all materials were free of charge for the customer. The thought was to reduce any barrier to entry to make the space as inviting as possible to the entire campus community. Slowly, the makerspace started to charge for materials. The intention was to recoup material expenses but not to make profit. First, button maker supplies were bundled and sold through the copy center that was adjacent to the space in the library. The fee was relatively low, $2.00 for materials to make ten buttons. Next, vinyl material for the cutter was sold to customers. It cost $5.00 for two linear feet of a 3-foot roll. The 3D printing is still free-of-charge for 3 hours of printing. The customer will likely be asked to pay a material fee for the 3D printer filament in the future, but there is currently not plan to do so. These measures have helped reduce the overall cost of running the makerspace, however labor costs are by far the largest recurring expense.

Conclusion

With the makerspace entering its third year of operations, it continues to provide valuable services to the campus community. The library manager continues to develop innovative programs and activities to bring in new users of the space. There is a game night, study hours, and smart TV for individual or group activities. A 3D pen was added to the equipment available for use in the makerspace. All the original equipment is working well and the 3D printers continue to be the most used resource aside from providing desks and chairs for studying.

Students have gained valuable experience working in the makerspace and have provided significant and valuable support to those wanting to make something and not knowing how.

Faculty continue to assign projects for their students that utilize equipment in the makerspace. While it can be difficult for the makerspace to accommodate a large class and an individually assigned project that must be made in the makerspace, the staff is willing to work with faculty to design appropriate assignments that meets the faculty's needs and are not overly burdensome to the makerspace equipment and personnel.

In the future, the makerspace will continue to develop new and innovative programming and look for equipment that aids student learning and development. The space is still limited to equipment that does not off-gas smoke or create sawdust but solderless electronic kits are likely to be added to the space in the near future as well as more support for computer programming, VR/AR, and sensors.

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