WORK IN PROGRESS: Design, Creation and Assessment of Innovation Spaces Across an Engineering Campus

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Introduction

The Maker movement has expanded over the last several years from the garages of at-home tinkerers to university engineering programs. A "maker" identity has been associated with specific attitudes and abilities, such as creativity, the ability to create physical models, and the embracing of failure, which engineering educators are now striving to foster in their students and throughout curricula.[1-3] Over the past ten years, makerspaces, or innovation spaces, have been developed at several universities across the United States through a range of efforts, both grassroots via faculty and student efforts, and institution-led. There have even been recently published best practices for designing these spaces within a university. [4] This work-in-progress paper focuses on one university's story of implementing makerspaces throughout a campus. It also contains initial data on how these spaces affect students' abilities to solve open-ended design challenges in the Mechanical Engineering department and will be later assessed in the Electrical Engineering department as well.

The Mechanical Engineering (ME) and Electrical Engineering and Computer Science (EECS) Departments at Colorado School of Mines have developed several high-tech and low-tech makerspaces for undergraduate students. These spaces are being utilized for classroom use and for club and do-it-yourself (DIY) projects. We have implemented state-of-the-art machine shops and prototyping labs throughout campus, funded by a combination of internal grants and industry support. These makerspaces have been grassroots efforts, started by both students and faculty in response to student requests for more incorporation of hands-on projects throughout the ME and EE curriculums and for spaces for students to use in their own time.

Due to the range of methods used to develop each of these spaces (spanning faculty-driven, administration-initiated, and faculty-student collaboration), we are in a unique position to document the processes and challenges of creating such spaces and the student-learning objectives achieved both within and outside the curriculum. In addition, each space is set up and used in a different way (an open, 24/7 accessible space versus a supervised space, a lab used for both instruction and student projects compared to one intended entirely for student use). This enables us to assess the impact of different forms of makerspaces on student outcomes such as confidence in hands-on projects and engineering design self-efficacy. The need for an understanding like this has been underlined by others in the field.[2]

In addition, the ME department has had an on-going IRB-approved study focusing on students' abilities to understand design and to solve open-ended design challenges. This study has shown powerful results as it began before makerspaces were incorporated throughout the college and campus. It focuses on identifying which courses students have

completed, which innovation spaces students have used, what the students' background is, and how students identify with an engineering design process. We have done both quantitative as well as quantitative analysis on students' confidence and ability to solve open-ended design challenges. By understanding where the student is in the curriculum along with what their background is (ie: internship, work experience, course work), we will be better able to understand how the makerspaces impact students' abilities to solve problems. By learning from our failures and documenting success, we have learned a tremendous amount about how to implement successful working makerspaces within a short time frame.

In this paper, we begin by describing the context for this effort at Colorado School of Mines and the various spaces that have been developed. We then compare each lab in detail, highlighting a few key differences. Finally, we discuss briefly efforts to assess the impact on student outcomes.

Background: The Maker Movement

Institutional Context

Colorado School of Mines is a small, STEM-focused, public university, which is known for its rigorous curriculum and hardworking students. For the past several years, there have been national efforts for universities with a strong focus in STEM to create makerspaces for student use in addition to creating courses that focus on learning-by-doing.[5]

This work focuses on four specific on-campus makerspaces at Colorado School of Mines: 1) a machine shop with traditional automated and manual equipment, 'The Machine Shop', 2) an interdisciplinary lab with 3-D printers and prototyping equipment called 'The Garage', 3) a low level prototyping lab for wood working and foam 'The Woodshop' (primarily used by a first year course taken by all engineering students on campus) and 4) an electrical-focused lab with oscilloscopes, microcontrollers, and signal generators called 'The Outlet.' The first three were developed in 2013 and have been in use for 2 years; the latter space was officially opened in the spring of 2016.

Though each of these spaces was created individually and separately, there are now efforts on campus to create a Maker ecosystem, tying together these distinct spaces through a new innovation website called M-Idea HUB. Thus, this work attempts to describe the benefits and challenges of this bottom-up approach and how an engineering college or university can best leverage this movement.

Details of the Spaces

The makerspaces at Colorado School of Mines are incredibly diverse in their objectives, how they were created, and how they are run on a day-to-day basis. This section illustrates this diversity, and highlights the benefits and drawbacks of each approach.

Origins

The first makerspace on campus was developed several years ago from an old machine shop in the basement of the college. Only a handful of students used this space every semester, and it felt more like a club than a space for all students in the college to use. In the fall of 2013, several faculty members put together internal and external proposals as well as Student Technology Fee (Tech Fee) proposals to revamp The Machine Shop in order to incorporate hands-on projects throughout the curriculum starting students' sophomore year. Several of these opportunities were funded, and in the Spring of 2014, The Machine Shop was revamped over several months. Additionally, several old pieces of equipment were replaced with new equipment. Starting in the Fall of 2014, three courses during students' sophomore and junior years were designed to included strong hands-on components, requiring students to use The Machine Shop space. The number of students using the space changed from around 20 students per semester to over 300+ students a semester. Online training programs were established as well as safety addressed to all students using the space. Additionally, the space has been staffed with a shop manager and a team of 9-11 undergraduate students who have expertise on at least one of the pieces of equipment. Their job is to check students into the shop, maintain safety, and train students on the piece of equipment they are experts on. Getting students into The Machine Shop ended up being very successful and the dean approved an addition that included four additional mills, four additional lathes, quality control equipment and station along with equipment for bending sheet metal and a finishing station.

Figure 1: The Machine Shop (back view)

Figure 2: The Machine Shop (front view)

Figure 3: The Annex of the Machine Shop.

Following The Machine Shop, it became clear that low-level prototyping spaces were needed on campus. Both The Garage and the EPICS workshop were developed during the Fall of 2014. The Garage was established through internal funding sources. The EPICS workshop, similar to The Machine Shop, had always existed, but was just not organized or staffed appropriately. The director of EPICS along with faculty within the college began working together to create an ecosystem of makerspaces, which all had various expertise, however held similar training and safety guidelines. At this point, a training and safety website was created join the three makerspaces together. Similar to The Machine Shop, undergraduate students were hired to help run both of these spaces, having individual students take ownership of at least one piece of equipment.

Figure 4: The Garage.

The idea for The Outlet (originally called the EECS Open Lab) originated from a departmental committee; the initial objective was to create an informal space for students, in order to cultivate teamwork, foster creativity, and life-long learning skills. This project quickly developed into one which was co-led by both faculty and students, with students assisting in writing internal equipment grants, brainstorming equipment needs, and generating ideas for how the lab should run. A student group (the IEEE Student Branch at Colorado School of Mines) led much of this effort. As evidence of the collaborative effort between students and faculty that has guided the development of The Outlet, the name was selected via a naming contest in which both students and faculty were given an opportunity to suggest a name for the space; a final name was chosen via a vote.

Figure 5: The Outlet.

Figure 6: The Outlet.

Equipment acquisition

Throughout the revamping of The Machine Shop, including the additional equipment that was spent on the expansion, well over $200,000 has been spent. The first round of spending included two new Haas Mini Mills along with a new lathe and upgrading equipment in the shop. This first round of spending, including software for the new CNC, was ~$115,000. Ever semester, new upgrades were made along with the a few new pieces of equipment that were deemed required by the students.

The Garage required an initial $15,000 worth of 3D printers along with refurbishing a laser cutter and an old 3D printer. Additionally, material testing equipment was purchased along with cameras, scanners and other technical equipment for student check-out. In total, $35,000 was spent on the initial set-up of The Garage.

The Woodshop already had all of the equipment that was needed. In order to revamp The Woodshop, time, organization and workers were required. During the summer of 2014, all faculty and students revamped the space, spending less than $5,000.

Of the approximately $55,000 that has been secured for The Outlet (this total includes donations or grants for specific equipment as well as donated discretionary funds), approximately a quarter has come from internal funds, with the remainder coming from industry donations. While the donated equipment has been welcome, the monetary donations have been instrumental in enabling the flexibility which a development of such a space requires.

Access and space

All four makerspaces have different times that they are open. This is mainly due to the time when support is available. All spaces are open at least 35 hours/week.

The Machine Shop is open from 8:30am-6pm, Monday-Friday. The Machine Shop requires, at a minimum, the shop manager who is a classified staff employee, in order for the doors to be open. Additionally, there are anywhere from 1-4 undergraduate student workers who assist throughout the day. For every undergraduate student worker working in the shop, there can be four students and up to two operating machines. No more than 12 students are allowed in The Machine Shop at once.

The Garage is open from 10am-5pm, Monday-Friday. This is an undergraduate student-run shop, with a faculty supervisor. Due to the low-level prototyping that goes on in the shop, The Garage only requires undergraduate student workers in order for the shop to be open.

The Woodshop is open from 9am-5pm, Monday-Friday. The Woodshop requires a faculty member to be present in the room if certain pieces of equipment are being used. The Woodshop consists of mostly low-level equipment, however there is a band-saw which requires support from faculty.

The Outlet is slated to be open 24 hours a day, seven days a week to students who have access through their student identification card. Access is given to students who sign a user agreement which contains the guidelines for use of the lab. Guests can be brought into the lab if they are accompanied by a Teslab user (someone who has ID card access) and sign in to a guest binder; the user has the ultimate responsibility for any guest they bring into the lab. Installation of a security camera is planned, due to the fact that the lab will be largely unsupervised.

A different policy has been created for a student group which plans to use The Outlet frequently for club meetings and projects. In this case, there will be certain pre-determined hours during which this group can bring in students affiliated with the group but who may not yet be users of the lab with 24/7 access. In this case, the club officers will agree to take full responsibility for the behavior of their members during the club hours.

Governance

As previously discussed, all labs are operated using undergraduate student workers. Some spaces, such as The Machine Shop and The Woodshop require a shop manager, while others such as The Garage and The Outlet have a faculty advisor assisting with the space. By having spaces that are student led, we have seen that students feel responsible for the space and feel privileged to have the space to use. Additionally, we have seen that students take 'pride in ownership', appreciating the spaces and helping to maintain the spaces. Additionally, with their input, students feedback and shown to be extraordinarily useful with advise as to new equipment that needs to be purchased or updated.

During the development of The Outlet, we have aimed to include students as much as possible, to give them a sense of ownership of the space (with the hope that this will lead to increased usage and responsible behavior). A Student Advisory Committee has been formed, to further the involvement of students.

Future Work: Assessment

The labs are currently being assessed separately, however it is thought that we will have better results if we assess the spaces in a similar manner as well. The Engineering Design Self-Efficacy Instrument is being employed as a form of pre-/post-assessment for The Outlet. The Machine Shop, The Garage and The Woodshop are all being assessed and evaluated based on a two year IRB study that began in 2013.[6] Upon assessing the students over two years, we have observed promising results that students abilities and confidence in working with their hands and solving open-ended design challenges, in the 1.5 years after the makerspaces have been open (The Machine Shop, The Garage and The Woodshop) and hands-on projects incorporated into courses. With this promising data, we will continue to follow these trends are more spaces open in addition to creating a similar study for EE. To stay consistent with EE, ME will also be employed as a form of

pre-/post-assessment as well. Additionally, as students prepare to graduate we will perform semi-structured interviews, to understand how they used the labs and any gains they showed in learning outcomes. This will be new for both ME as well as EE.

Conclusions

From the efforts at Colorado School of Mines, a number of conclusions can be drawn:

- Makerspaces can successfully be established through both student and faculty led efforts.
- Implementing hands-on projects throughout the curriculum will increase the number of students who start using the space/s and continue to use the space/s.
- Establishing safety throughout several different makerspaces can be successful if similar safety plans and training programs are disseminated throughout campus.
- Even if a makerspace is held within a particular department, students from other departments will use the space if allowed and asked to (through curricular aspects).
- If we provide students with a sense of ownership, they will help maintain the space.
- Having various makerspaces on campus housed in various departments and buildings around campus is a model that works if both faculty and students work together.

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