



Academic Maker Spaces and Engineering Design

Dr. Vincent Wilczynski, Yale University

Vincent Wilczynski is the Deputy Dean of the Yale School of Engineering and Applied Science and the James S. Tyler Director of the Yale Center for Engineering Innovation & Design. As the Deputy Dean, he helps plan and implement all academic initiatives at the School. In addition, he manages the School's teaching and research resources and facilities. As the James S. Tyler Director of the Center for Engineering Innovation & Design he leads the School's efforts to promote collaboration, creativity, design and manufacturing activities at Yale's academic makerspace. His professional interests in Mechanical Engineering are in the areas of data acquisition/analysis and mechanical design. He is the Co-Chair of the Executive Advisory Board of the FIRST Foundation and is a Fellow of the American Society of Mechanical Engineering. Previously, he was the Dean of Engineering at the U.S. Coast Guard Academy and has had fellowships at the MIT Charles Stark Draper Laboratory, the Harvard School of Public Health and with the American Council on Education. He has also served as the Vice President of Public Awareness for the American Society of Mechanical Engineers and was the 2001 Baccalaureate College Professor of the Year by the Carnegie Foundation, the only national award that recognizes outstanding college teaching.

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Abstract

The arrival of academic makerspaces on college campuses signals an important development for engineering design education. On a growing number of campuses, traditional machine shop equipment has been combined with digital design and manufacturing tools to establish creative communities. These communities support academic, extracurricular and personal design activities under the watch of university faculty, staff, and students. As awareness of the value of academic makerspaces increases in academic and non-academic settings, a larger number of universities are developing these new facilities for learning and creating, often with unique institutional purposes. This paper reviews facilities at Arizona State University, Georgia Institute of Technology, Massachusetts Institute of Technology, Northwestern University, Rice University, Stanford University, and Yale University and highlights the unique attributes of each institution's academic makerspace.

Introduction

Nationwide there is an increasing number of individuals who want to design and fabricate physical objects. These skills are now more readily attainable because of advances in three key technologies: design software, manufacturing tools, and integrated control systems. Intuitive computer-aided design software programs provide users with an ability to quickly master basic functions and design sophisticated systems. Once designed, components can be manufactured (and some automatically) with a variety of traditional and modern machines including 3D printers; laser, water and plasma cutters; and computer controlled mills, lathes and routers. Sensors that measure nearly any physical parameter can then be readily integrated with systems to monitor and control functions.

Access to manufacturing technology has been made easier due to a convergence of factors, including the ease of use of tools, reductions in the cost of manufacturing equipment, the development of integrated systems (especially with regards to software file-sharing compatibilities), and the availability of open-source training. These factors have promoted developments not only within manufacturing centers and universities, but more broadly throughout society. A proliferation of individuals who are interested in the creation, design, and fabrication of new objects has evolved into the self-branded "Maker Movement."¹

Using Maker Movement nomenclature, "makers" are individuals who design and build new devices, and share their experiences with one another. A "makerspace" is a physical location that serves as a meeting space for a "maker community" and houses the community's design and manufacturing equipment. Such spaces are commonly community-organized with the community determining its structure, function, programming, and funding. In addition to being a physical space for members to meet and use equipment, a makerspace typically offers training

and certification programs to teach new skills. As a community organization, makerspaces provide access to technology, training to use technology, inspiration for ideas, and support to help members pursue design projects.

The idea of assembling individuals from a variety of backgrounds and talents while providing access to technology for the sake of promoting creativity is not a new concept. As an historic example, the Bell Labs “Black Box” research facility featured open corridors, glass perimeters around labs, and open meeting spaces to promote a “serendipitous collision of ideas.”² What distinguishes the modern manifestation of this approach to discovery and creating is the drive of individuals rather than corporations to create new contemporary affiliations that catalyze creativity.

The modern ease of access to technology has produced a large number of new makers and has led to the formation of many maker communities. Several aspects of this phenomenon have been recorded (and to a certain degree organized) by the popular press. For example, *Popular Mechanics*, *Popular Science*, and *Wired* magazines modified their print and web formats based on this new interest, adopting the branding label DIY (Do It Yourself) to appeal to segments of this growing market. Central to the Maker Movement is the concept of DIWO (Do It With Others), with this acronym now becoming popular in the press.

Of particular note is the rise of the “*Make*: enterprise” which originated as a magazine of the same name but has now expanded to include products, workshops, and training to support maker communities. As the lead organization of the otherwise unassociated bands of makers and their communities, *Make*: advocates the following tenants: making is a community activity, making is not competitive, failure is embraced as a step towards success, and making is available for everyone.³ In addition to the print and online material, *Make*: popularized the concept of community-based *Maker Faires* where members gather to exhibit, teach, and learn. The legitimacy of the *Maker Faire* concept was highlighted in 2014 when the inaugural White House *Maker Faire* was hosted by President Obama at the executive residence.

Increased interest in this subject has promoted growth in the supply side of these endeavors. Recently founded commercial venues cater to the maker community, supplying individuals with the components and training to design and build systems. Such vendors offer products well beyond manufacturing tools (such as consumer market 3D printers) and include microprocessors, interface boards, and supplies to construct electromechanical and embedded systems. Though the Maker Movement is not centralized and there is no official measure of its size, these examples indirectly indicate that a growing number of individuals are indeed making things and doing so in community-based settings.

Makerspaces within the Academic Community

Universities have always provided elements of the now popular makerspaces, including machine shops, assembly/testing areas, CAD labs, meeting spaces, and classrooms. What universities

have not always done is include all of these elements in one location and make the resulting space widely accessible to an academically diverse campus population. Influenced by the rising societal interest in “making” and supported by a long list of design-focused initiatives within engineering education, a number of colleges are now planning and building “academic makerspaces.”

Before examining the impact of academic makerspaces on college campuses, it is important to review the landscape that contributed to the creation of such spaces. The increased attention to the role of design throughout the engineering curriculum advocated for by accreditation commissions has helped produce change.⁴ This influence prompted engineering educators to expand instruction beyond theory into applications, with an associated increase in course content that included design-test-build activities.

Paralleling the accreditation driven move to increase design content in the undergraduate engineering curriculum, the concepts of problem-based learning and service learning also became popular approaches to connect course material with field applications, often using client-driven scenarios and open-ended challenges.^{5,6} This attention to increasing student engagement was in part prompted by an increased awareness of the value of active learning and team-based problem solving.

These initiatives manifested themselves in a variety of fashions, including improving student experiences using cornerstone and capstone design projects as well as the creation of U.S. Government sponsored initiatives. For example, the grant-funded “Learning Factory” project was developed to simultaneously create a practice-based curriculum and the supporting physical facilities required to design/fabricate new products.⁷ Of note was the significant cost (in the late 1990s) to create facilities that could integrate design, manufacturing, and business development. Advances in all of these areas have since reduced entry barriers and democratized product development, thereby fueling the Maker Movement.

A more recent influencing factor in the trend to advance engineering student design skills is the rise in student entrepreneurial interests. While translational and cooperative research had historically been a university-led function that centered on faculty research, many institutions have recently expanded their support for both faculty-led and student-led entrepreneurship activities. As a result, there is a growing need for facilities that allow students to develop their independent design projects and create prototypes of the products they are working to commercialize.

Collectively this set of factors has increased student desires to access technology that supports hands-on work within and beyond the curriculum. Combined with these factors, the Maker Movement has also influenced engineering design education and, in some cases, accelerated a culture shift on college campuses. That culture is one that promotes hands-on learning, is open to new ideas, welcomes diversity within problem-solving teams, shares techniques and results,

values teamwork, and is multi-disciplinary. Fundamental to this culture shift has been the establishment of collaborative spaces for individuals and teams to learn, work, and share: locations that are referred to as “academic makerspaces.”

Academic makerspaces have a variety of names which use words such as design, innovation, creativity, and invention as adjectives for the labs, centers, and studios, as well as the more creative descriptors of gymnasiums and kitchens, that house these communities. No matter what they are called, these spaces have similar infrastructure, programming, and functions. The specifics of each academic makerspace, including focus, access, and staffing vary with each institution.

These spaces usually include traditional and modern manufacturing equipment, as well as digital design tools to support the academic, extracurricular, and personal design activities of university students, faculty, and staff. The community nature and openness of these spaces is an important distinction. In academic makerspaces, community members formally and informally learn from one another in a variety of classroom, workshop, and open-studio formats.

A review of the unique attributes of a collection of academic makerspaces is presented in the following sections as models for institutions that are planning to create academic makerspaces. The review does not detail the equipment, programs or operating policies for each reported space but rather highlights the uniqueness of each institutional entity. This review is not intended to be a complete record of the Maker Movement on college campuses. As an example of that scope, over 150 colleges and universities detailed their contributions to the Maker Movement in reports cataloged by the Executive Office of the White House.⁸

Academic Makerspace Model: Massachusetts Institute of Technology

The Massachusetts Institute of Technology does not have a singular academic makerspace on its campus, but a network of small makerspaces strategically located across campus is a key aspect of MIT’s long range plan.⁹ This plan details embedding the future spaces within academic villages that include classrooms, meeting and study spaces, technical and library support, and food service. The academic villages are based on a concept that “blended learning” requires “blended spaces.” Given MIT’s codified approach to learning that combines the work of the mind and the hand, incorporating academic makerspaces into planned learning communities is a direction that aligns with the institution’s purpose.

The lack of an academic makerspace on MIT’s campus stems from the fact that since its inception MIT has promoted hands-on learning. As a result of this focus, MIT has created many teaching and research facilities to support this approach to learning, though such facilities are generally associated with single entities, be that a discipline, course, medium (such as glass, wood, or metal) or purpose (such as research, student association, or hobby). Given this history, two facilities at MIT are noteworthy examples that partially fulfill the function of an academic

makerspace: MIT's Pappalardo Lab and a facility managed by the MIT Electronics Research Society.

The MIT Pappalardo Lab is a combined design studio, meeting space, and manufacturing center that supports high enrollment (150+ students/semester) design courses.¹⁰ This lab primarily supports cornerstone and capstone project-based courses in the Mechanical Engineering major (2.007: Design & Manufacturing and 2.009: Product Engineering Processes) as well as intercessional programs in design and manufacturing (for MIT students during January and outreach students during the summer). The facility includes an open studio (for project work), an adjoining machine shop, and adjacent meeting rooms. Storage for designed systems, supplies, and stock is incorporated into the space. The machine shop, which is connected to the work studio, is only open during hours when the professional staff is on site, with those hours expanded at the end of the semester. This facility is a component of MIT's Department of Mechanical Engineering and primarily serves that segment of the MIT student population.



Figure 1. MIT: Pappalardo Lab

The Pappalardo Lab can be characterized as a notable academic makerspace for its level of staffing and its training programs. The lab is staffed by six fulltime manufacturing educators who provide training and instruction in using the facility's equipment. This staff augments each course's teaching and support team to provide education, training, and oversight. Because of the large number of students that use the space and the course turnover each term, equipment training and certification instruction is regularly conducted in the lab, thereby making this facility's training system an exemplary model for certifying a large number of users on a

periodic basis. Also noteworthy about this facility are the resources deeded to the users, with each team assigned its own work bench, storage lockers, tools, and whiteboard for the duration of the project (course).

Very different from this academic facility is the site managed by the MIT Electronics Research Society (MITERS) student organization. While MITERS historically was associated with electronic devices, it is now an organization that supports student design initiatives by providing access to a mill, lathe, band saw, welding equipment, hand tools, and bench-top electronics equipment. The oversight of and funding for this facility is accomplished solely by students (with a student-run electronics recycling program being its primary funding mechanism).

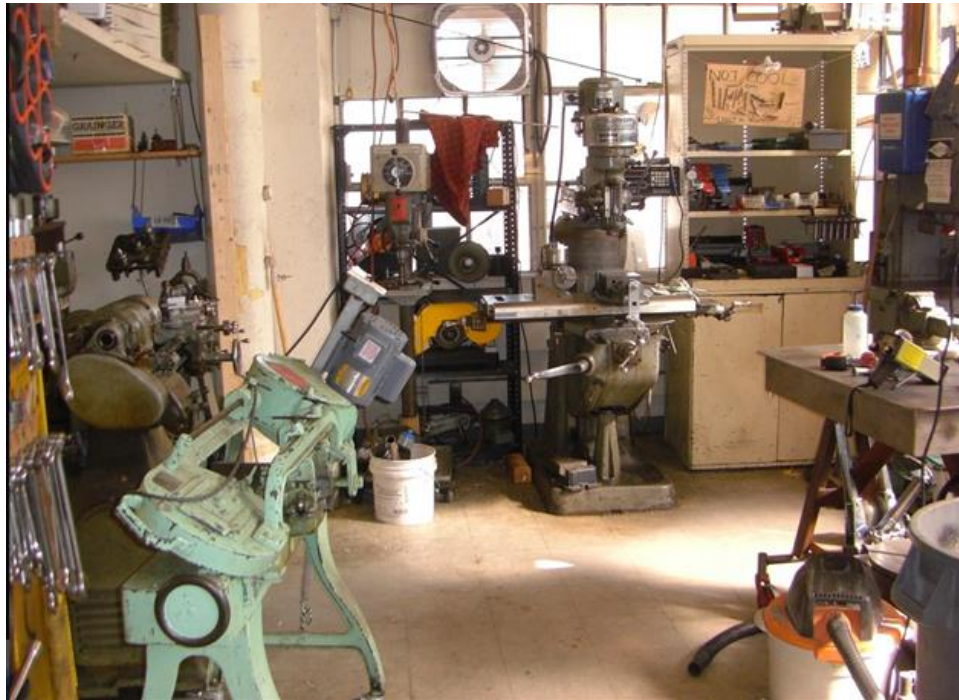


Figure 2. MIT Electronics Research Society Workshop

The projects completed in the MITERS facility are often whimsical and technically sophisticated pursuits of individual members who engaged in such work as personal activities (unassociated with courses or engineering student clubs).¹¹ Rarely is the facility used to support curriculum or research activities. Given its purpose to support student design interests, this facility perhaps qualifies to be called an academic makerspace but that title may not be appropriate due to a unique attribute of the facility. The MITERS workshop operates nearly independent from MIT, with the student members directing all aspects of its operation. This organizational structure is more reflective of that found in community-based makerspaces outside of the academic environment.

What is striking in these two examples from the same institution is their very different organizational models, each driven by the facility's primary purpose. While the Pappalardo Lab

is staffed by professionals and supports academic projects, the MITERS shop is student-operated and supports the creative needs of its student members. These examples illustrate how the fundamental purpose of a facility determines structure and organization.

Academic Makerspace Model: Stanford University

Like at MIT, a number of facilities at Stanford University focus on the acquisition and development of design and manufacturing skills. Two facilities at Stanford University have unique attributes related to academic makerspaces.



Figure 3. Stanford University: Product Realization Lab

The Stanford Product Realization Lab, a descendent of the Student Shops from Stanford's 1891 founding, developed into a comprehensive educational component of the Mechanical Engineering Department nearly 40 years ago. The Stanford Product Realization Lab is a collection of shops that provides machine and tool access, training (including but not limited to video tutorials), and materials for designing and manufacturing.¹² The supported manufacturing processes include laser cutting, additive manufacturing, casting, machining, welding, forming, woodworking, electronics, finishing, plastic working, sewing, and vinyl cutting. In addition to tools and training, the Product Realization Lab also hosts a series of events including student presentations, design lectures, and "Meet the Makers Expert Sessions" to increase skills and product design awareness.

As an organizational component of the Department of Mechanical Engineering, the lab primarily services departmental courses, with this alignment being its unique attribute. While the reported academic facility at MIT supported one course each semester, the Product Realization Lab supports all of the mechanical engineering department's design courses each semester. In

addition, the lab also supports a small number of design-build courses offered by Stanford's Department of Art. Access is provided for students enrolled in these courses as well as for any Stanford student through an open access program (during scheduled work periods in specific shop areas). As the single facility for all design courses in the Department of Mechanical Engineering, the Product Realization Lab provides an efficient method for delivering consistent instruction in machine use, safety, and manufacturing techniques. With its focus on learning how to make while designing and manufacturing, the lab provides a baseline set of expectations and resources for the program's students.

Similar to the organizational structure of the Stanford Product Realization Lab, the Stanford d-school (which is officially titled the Hasso Plattner Institute of Design and is not one of Stanford's professional schools) is a component of the Department of Mechanical Engineering. The Stanford d-school offers academic courses (open to all Stanford students), hosts a robust set of corporate and academic outreach education sessions, and is the institutional home for some national design initiatives.



Figure 4. Stanford University: d-school

The unique attribute of the Stanford d-school relative to the academic makerspace discussion is the program's focus on “innovators and not innovations.”¹³ The Stanford d-school emphasizes design thinking as a team-based problem solving technique throughout the program's courses, web resources, and workshops. The emphasis on methods as opposed to products is fundamental to all activities conducted within the d-school. The d-school does not have much of the manufacturing equipment found in a typical academic makerspace, with the d-school's fabrication equipment inventory limited to hand tools for early stage prototyping of concepts.

The facilities at these institutions illustrate a unique academic makerspace characteristic:

- course specific focus (MIT Pappalardo Lab)
- infrastructure to support extra-curricular efforts (MITERS facility)
- infrastructure to support curricular and co-curricular design activities (Stanford PDL)
- design methodology instruction (Stanford d-school)

The remaining profiled institutions generally combine aspects of these functions in their academic makerspaces.

Academic Makerspace Model: Georgia Institute of Technology's Invention Studio

The Georgia Institute of Technology's Invention Studio is a 3,000 square foot facility that includes design and manufacturing equipment for students at all levels and in all disciplines.¹⁴ The Invention Studio falls under the oversight of the George W. Woodruff School of Mechanical Engineering at Georgia Tech, similar to the reported facilities at MIT and Stanford. Funding for establishing and maintaining the studio is provided by the mechanical engineering program's capstone design course where industry sponsors fund student teams to investigate topics of interest to the sponsoring companies. These funds not only cover the specific project costs, but also provide overhead support for the design and fabrication studio where the work is conducted.



Figure 5. Georgia Institute of Technology: Invention Studio

The Georgia Tech Invention Studio is unique in that the facility, which is supported by the mechanical engineering program, is primarily student-run. Maintenance and general oversight of the equipment is provided by the mechanical engineering program but the day-to-day operation of the facility, including supervising students using equipment in the space, is under the purview of expertly trained undergraduate students who work in the Invention Studio. The space and its

equipment (which includes 3D printers and industrial mills and lathes) is available 24/7 to the expertly trained student instructors. All other students have access to space on a regular basis during the week. Free access is available to students from all disciplines to work on curricular and personal projects. The openness of the facility has contributed to a cultural transformation on campus, with recorded positive impacts on student engagement in engineering disciplines and a marked increase in student manufacturing skills.¹⁵

Academic Makerspace Model: Northwestern University's Segal Design Institute

Human-centered design projects are the primary focus of the Segal Design Institute at Northwestern University which is housed in the Ford Motor Company Engineering Design Center. The institute is functionally a component of Northwestern University's McCormick School of Engineering & Applied Science and is closely affiliated with the Department of Mechanical Engineering. The institute provides design resources as well as collaboration space to facilitate innovative problem solving. Central to the institute is the Prototyping and Fabrication Lab which consists of a machine shop and a project assembly area. Additive manufacturing equipment, mechatronics support, CAD/CAM software, CNC mills and lathes, a laser cutter, welding equipment, and a paint booth are also available. The facilities are used for courses, graduate research, and student engineering association projects.¹⁶



Figure 6. Northwestern University: Segal Design Institute

The unique attribute of the Segal Design Institute is its role as an interdisciplinary academic unit that grants specific degrees. For example, the Segal Design Institute offers a B.S. degree in Manufacturing & Design Engineering, two Master's degrees (Master of Science in Engineering Design & Innovation and Master of Product Design & Development), and supports a Ph.D.

research program. The institute also sponsors a dual-degree program (MS in Design Innovation and an MBA) in partnership with Northwestern University's Kellogg School of Management. With the exception of the MBA degree, all degrees are awarded by Northwestern University's McCormick School of Engineering. This academic emphasis and the alignment of its design curriculum with the degree-granting aspects of the university is a unique attribute of the Segal Design Institute.

Academic Makerspace Model: Rice University's Oshman Engineering Design Kitchen

The focus of Rice University's Oshman Engineering Design Kitchen is to provide undergraduate students majoring in engineering, computer science, and applied math with the ability to design, manufacture, test, and deploy solutions to real-world problems.¹⁷ At 18,000 square feet, this facility is among the largest campus spaces devoted to developing undergraduate design skills. The Oshman Engineering Design Kitchen includes a classroom, meeting rooms, a wet lab, and a number of workshops. With a full time staff of ten, including three Ph.D.-level staff members, the Oshman Engineering Design Kitchen provides technology and a large support team to guide students. Access is granted to students who are enrolled in Oshman Engineering Design Kitchen courses, team members working on approved projects, and graduate students working on research projects.



Figure 7. Rice University: Oshman Engineering Design Kitchen

A defining attribute of the facility is its commitment to a diverse population of engineers, material scientists, applied mathematicians, and computer scientists. Within the School of Engineering & Applied Science at Rice University, the facility supports not only mechanical and electrical/computer engineering students, but also students majoring in chemical/biomolecular

engineering, bioengineering, civil/environmental engineering, statistics, computational/applied mathematics, computer science, and materials science/nanoengineering. Supporting this wide range of technical disciplines requires specific equipment, such as that housed in the facility's wet lab, as well as workshops and programs that appeal to a diverse membership base.

Academic Makerspace Model: Arizona State University and TechShop

“TechShop” is a commercial endeavor that provides access to a makerspace based on a subscription model, similar to that used by other membership-based businesses such as health clubs. The member's monthly membership fee allows unlimited access to the facility and its equipment. Certification to use specific pieces of equipment, such as mills and water jet cutters, is provided once members are trained on the particular piece of equipment (with an additional cost for most training sessions). The concept of a subscription-based makerspace is relatively new, with fewer than 10 locations currently in operation across the U.S.



Figure 8. Arizona State University and TechShop

Arizona State University joined with the Chandler TechShop and a public-private partnership (ASU Chandler Innovation Center) to provide makerspace access for ASU students.^{18,19} The partnership provides access to 35,000 square feet of state of the art fabrication equipment and software to support courses, workshops, and events. The partnership intends to advance innovative learning and interdisciplinary education programs in engineering, management, and entrepreneurship at ASU. This partnership is the first between the commercial entity TechShop and an academic institution. Opened in the fall of 2014, the operating parameters are currently being established and refined. Though in its infancy, this partnership represents a unique method to establish and operate an academic makerspace.

Academic Makerspace Model: Yale University's Center for Engineering Innovation and Design

The Yale Center for Engineering Innovation and Design opened in 2012 as a university resource to catalyze design, creativity, and engineering activities.²⁰ As one component of a faculty-developed strategic plan, the Center for Engineering Innovation and Design (CEID) was established to help advance the engineering culture on campus. The center is housed in and managed by the School of Engineering & Applied Science and is available to any member of the Yale community. Members of the CEID have 24/7 access to the center's design studio and meeting spaces, with access to the fabrication equipment (beyond hand tools and 3D printers) restricted to times when one of the CEID's full-time shop supervisors is present. In addition to the infrastructure, the CEID hosts design-centered classes, offers workshops, supports student organizations, and provides consulting assistance to its members. CEID members are allowed to use the facility for course, club, research, and personal projects, with an expectation that they share their work with others.^{21,22}



Figure 9. Yale University: Center for Engineering Innovation and Design

The university-wide access structure is a unique attribute of this facility. Undergraduate students from all disciplines and graduate students from the majority of Yale's professional schools are members of the CEID. The design courses taught in the CEID encourage university-wide participation and include classes on social entrepreneurship (jointly taught by faculty from Engineering and Global Affairs), the design of musical instruments (taught by Engineering & Department of Music faculty), medical device design (with instructors from Engineering and the School of Medicine), and using light as an art form (led by School of Art and Engineering

instructors). The Yale CEID has had a dramatic effect raising the culture for engineering at Yale and has developed as the university's hub for creativity and innovation.

Observations

While some of these programs (such as those at MIT and Stanford University) have existed for decades, there is new interest in establishing spaces for students to collaborate, design, manufacture, and share. Table 1 summarizes aspects of the profiled academic makerspaces. The ASU-TechShop example was not included in the tabulated summary due to its commercial origin. These examples illustrate a variety of models for incorporating academic makerspaces on college campuses.

This review suggests a number of best practices that can be incorporated at existing and planned spaces. ***The mission of the academic makerspace must be clearly defined*** from the onset, with the space then designed around that mission. The Stanford Product Realization Lab example illustrates how a traditional machine shop (in this case with an 1891 origin) can be adapted to serve as an academic makerspace by hosting courses and creating a self-sustaining culture of users to share information and develop fabrication skills. The example at Rice University illustrates how the physical site can be used to establish a design culture, in this case across nine different majors. To address this issue, the design of the Rice University facility included components to draw in all majors, with the wet lab a key aspect of that plan.

The most successful academic makerspaces ***ensure that the facility is properly staffed*** with educators, manufacturing and design professionals, and administrative support. The impact of an academic makerspace on a campus correlates with the staff support provided in the space. As evidenced in the presented examples, multi-talented staff support is needed to offer instruction, training, supervision, and programming within the space. Providing adequate staff support is an important consideration when planning, funding, and operating academic makerspaces.

Open environments promote collaboration within academic makerspaces. The images detailed in this paper illustrate that large open areas are common within academic makerspaces to promote the awareness of activities, projects, and interests. Such spaces spur dialog and idea exchange since one's work is conducted in a public venue. The open architecture format that is favored in academic makerspaces has even greater value when workstations are mobile, thereby allowing options to arrange the space to best fit changing needs. The profiled examples include membership models where students from a variety of academic programs use the space and, as a result, offer diverse perspectives for amplifying creativity and solving problems.

Aligning access times with the student work schedules increases the utility of academic makerspaces. Academic makerspaces can operate with non-standard access schedules, including 24/7 access to the facility. Access to academic makerspaces is generally limited to trained and

authenticated members of the community, with additional training required to use specific manufacturing equipment.

Providing user training is essential to making academic makerspaces productive. This training often takes the form of staff-delivered training modules for each piece of equipment. The training can also include student-delivered workshops on programming, CAD, or other technical topics of interest to the local academic makerspace community. While the training provides individuals with new skills, it also serves as a mechanism to further establish and foster the maker culture on campus. In this context, the training sessions have important social purposes as forums for campus makers to meet one another and as a mechanism for community building.

Attention must be devoted to establish a maker community on campus, with the academic makerspace being one component of that community. Interactions between members of an academic makerspace are the most valuable component of these endeavors. The community of like-minded creators has the potential to fuel itself, with the members teaching each other and serving as resources to spawn new ideas. The operation of the academic makerspace can help create and strengthen this community by offering programming that connects members and eliminate barriers.

While the purpose of this paper was to detail unique attributes of existing academic makerspaces as a guide for planning new spaces, this review also suggests there is great value in studying and cataloging best practices of such spaces. The list of best practices can include outfitting, training, programming, safety, financing, and staffing models that allow others to benefit from the collected practices. Given the proliferation of academic makerspaces, it is expected that these facilities will continue to influence the engineering education landscape. Documenting and sharing academic makerspace best practices has potential to accelerate that impact.

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Table 1. Characteristics of institutional academic makerspaces

FACILITY	MIT Pappalardo Lab	MIT MITERS	Stanford Product Realization Lab	Stanford d-school¹
Host unit	ME Dept	students	ME Dept	ME Dept
Staff	4 FTE	40 students	6 FTE	69
Disciplines	ME	all	all	all
Size (sq ft)	20,000	1,000	not available	24,000
Established	1995	1973	circa 1970	2005
Traditional manufacturing	Y	Y	Y	N
Additive manufacturing	Y	Y	Y	N
Dedicated team meeting space	Y	N	Y	Y
Academic courses supported	3 ME courses taught in the space	none	8 ME courses ² taught in the space	supports 30 courses from multiple depts.
Workshop presentations	N	Y	Y	Y
Access: people	course enrollment	club members	open-access	course enrollment
Access: time	M-F 8AM-5PM T&W 6PM-9PM	24/7	8AM-11PM, every day	M-F 9AM-5PM
Use	course projects	personal projects	course, club, personal & research projects	course projects
Users	Course enrollment (est. 400/yr)	40 members	1,700 members	650/yr
Finances	dept. funded	club funded	\$100/yr member fee	“school” funded
Uniqueness	exclusively supports 3 ME courses user training program	student-run student-funded	university-wide access sponsored by a department	Design Thinking focus

¹ Official name: Hasso Plattner Institute of Design

² Support 9 additional ME courses and 3 Art courses

Table 1 (cont.). Characteristics of institutional academic makerspaces

FACILITY	GA Tech Invention Studio	Northwestern Univ. Segal Design Institute	Rice Univ. Oshman Engineering Design Kitchen	Yale Center for Eng Innovation & Design
Host unit	School of ME	School of Eng.	School of Eng.	School of Eng.
Staff	1.5 FTE 80 Students (PT)	14 FTE	10 FTE	4.5 FTE
Disciplines	all	all	Rice Engineering ³	all
Size (sq ft)	3,000	20,000	18,000	8,500
Established	2009	2007	2008	2012
Traditional manufacturing	Y	Y	Y	Y
Additive manufacturing	Y	Y	Y	Y
Dedicated team meeting space	N	Y	Y	Y
Academic courses supported	supports 25 courses each semester	49 graduate and undergraduate courses	14 courses taught in the space & supports 10 additional courses	10 courses taught in the space & supports other courses
Workshop presentations	Y	N	Y	Y
Access: people	open access	course enrollment, project teams, researchers	course enrollment, project teams, researchers	open-access
Access: time	M-F 10AM-6PM 24/7 for student staff	M-F 8AM – 7PM	24/7 except for machine shop (M-F 8AM 7PM)	24/7 except for machine shop (staffed hours)
Use	course, club, personal & research projects	course, club & research projects	course, club, research & approved design projects	course, club, personal & research projects
Users	1000 students/semester	1,500	1,000	1,200 members
Finances	multiple sources ⁴	school funded	school funded, w/ industry sponsors	school funded
Uniqueness	primarily student-managed	offers undergrad & graduate degrees	serves 9 engineering majors	university-wide membership encourages collaboration

³ Bioengineering, Chemical and Biomolecular Engineering, Civil and Environmental Engineering, Computational & Applied Mathematics, Computer Science, Electrical and Computer Engineering, Materials Science & Nano-Engineering, Mechanical Engineering, and Statistics

⁴ Industry, student technology fee & research reimbursement funded