Advances in Engineering Education

SPRING 2020

Case Study: Maker Space Management by Minions

DUSTYN ROBERTS
University of Pennsylvania
Philadelphia, PA

AND

JENNI BUCKLEY
University of Delaware
Newark, DE

ABSTRACT

The Design Studio is an academic makerspace, housed in the Mechanical Engineering Department at University of Delaware, that was co-developed through a multi-year, grassroots effort by the department and its undergraduate study body. It originated in 2012 in a small, under-utilized study room and evolved in stages into its present form as a 5,500 square foot, all-access makerspace, with designated areas for digital manufacture, electronics, carpentry, metal working, wet lab, and mechanical testing. The bulk of the expansions, room renovations, and major equipment purchases were completed on a modest budget ($160k total), drawn primarily from alumni donations and departmental funds. Undergraduate students (the Minions) have been integral to the design, construction, maintenance, and daily operation of the Design Studio since its inception in 2012 to the present. The Minions have grown into a small army of undergraduate assistants, and they rather independently manage safety, inventory, and day-to-day operations under the supervision of two faculty co-directors. The Design Studio is now utilized by nearly 80% of the core courses within the department for labs, design projects, and demos. The space is also the de facto study and collaboration space for the majority of our undergraduate population as well as the home of many of our student organizations. The Design Studio itself is a student-centered design project, and as such, it is inherently a work-in-progress. Therefore, the purpose of this case study is not to prescribe our particular pathway for creating and maintaining an academic makerspace. Rather, we present this case study in the hopes that other institutions with similar design constraints – whether they be space, funding, or staffing – actively engage their own student body (Minions) in creating a makerspace that works in their community.

Key words: Design Studio, Mechanical Engineering, Student Centered

INTRODUCTION

Academic makerspaces, design centers, innovation institutes, and creativity labs of different kinds are becoming popular hubs of activity on many campuses, particularly within engineering colleges and departments. Some of these centers, such as Stanford's d-school [1] and Penn State's Learning Factory [2]–[4], have existed for over a decade. Others, such as Yale's Engineering Design Center [5] and Georgia Tech's Invention Studio [6], are relatively recent developments. These spaces generally offer a physical location with fabrication resources and support for students to learn and work in a hands-on environment. However, they are more than just fabrication facilities because a key element of a makerspace is the community itself. In other words, the people matter just as much as (or more so than) the machines. A participatory culture that encourages informal interactions between the communities that the makerspace serves is what distinguishes it from a facility used only for fabrication.

The Design Studio is a unique academic makerspace in the University of Delaware Department of Mechanical Engineering that was designed, built, and maintained as a partnership between the undergraduate student body and the faculty [7], [8]. The space was created and is maintained under tight budgetary, staffing, and space constraints, all of which make student-faculty collaboration essential. Our experience is that a team of engaged students (the Minions [9]) are not merely the end-users of an academic makerspace, they are the creators and co-owners of it. Our experience is that a participatory culture should not just be encouraged after an academic makerspace is constructed; it should drive the creation of the space itself.

EVOLUTION OF THE DESIGN STUDIO

The Design Studio at University of Delaware originated as a pilot project in 2012 to convert a small, under-utilized senior-year study lounge (Room 109 in **Figure 1**) in the Mechanical Engineering Department's main building (Spencer Laboratory) into a light-duty fabrication area for student design projects. The department invested modest funding ($10,000) towards fixtures, hand and power tools, and a hobby-grade 3D printer; and undergraduate students volunteered for several weeks during the off-term to perform minor renovations (e.g., painting walls, hanging shelving, and assembling fixtures). The repurposed space was immediately popular with students in the capstone and freshmen design courses due to its all-hours accessibility and unrestricted use of tools and materials.

Based on a successful pilot year, the department supported the staged expansion of the Design Studio. Conveniently, faculty in adjacent laboratory spaces were relocating to newer facilities, leaving physical space available for expansion. The department allowed the Design Studio to occupy the space – again as a pilot experiment – and the decision was made to purchase and install only modular furniture and fixtures to allow for efficient and cost-effective relocation if the space were eventually reabsorbed as research laboratories. The layout for the prototyping areas was influenced by Penn State's Learning Factory [2]–[4], and collaboration and student study spaces by Stanford's D-Studio [1].

A total of six expansions and renovations occurred between 2013 to present. In 2013, a carpentry and tool crib area (The Cage) was created, and better quality 3D printers were acquired through an institutional grant. In 2014 and 2015, a light-duty prototyping and collaboration space (The Pit) was added, and our growing portfolio of digital manufacturing and electronics equipment was relocated to an adjacent room (The Fab Lab). A biomechanics and human factors design area (The Matrix) was acquired in partnership with the Biomedical Engineering Department to support a capstone design program between the two departments. The space was designed for wet lab (BSL-1) work as well as light duty prototyping and outfitted with more medically-focused equipment and supplies, e.g., dissection tools, freezers, and anatomical models. In 2016, the Design Studio was awarded a large institutional grant ($660k, UniDel Foundation), which was primarily allocated towards upgraded CNC metal working equipment in the student-shop (80% of award). At this time, the Student Shop and Mechanical Systems Lab were formally incorporated into the Design Studio, and a design validation space was created (The Test Lab) and equipped with multiple materials testing machines and plug-and-play sensors. Funds were also used to relocate and again renovate core student prototyping and collaboration areas, e.g., The Fab Lab and The Pit.

The Design Studio had evolved into its present footprint by Fall 2016, after undergoing the six aforementioned expansions. With each expansion, the Design Studio became less of a pilot project and more of an essential resource within the department. The facility and its resources are now a permanent fixture of our program. The total departmental investment in the Design Studio to date has been $160k, with approximately 50% from new alumni donations and the balance from general funds. Student labor and input was critical in every staged expansion of the Studio and led to substantial cost savings. A team of 4-6 students typically worked for pay over the off-terms on renovations. These students provided valuable input into room functionality and workflow, minimizing the need for costly and disruptive redesigns during the semesters. Prior to each renovation, we also solicited input from the de facto student organization (The Mechanical Engineering Student Squad – The MESS) on intended room usage and equipment and supply needs.

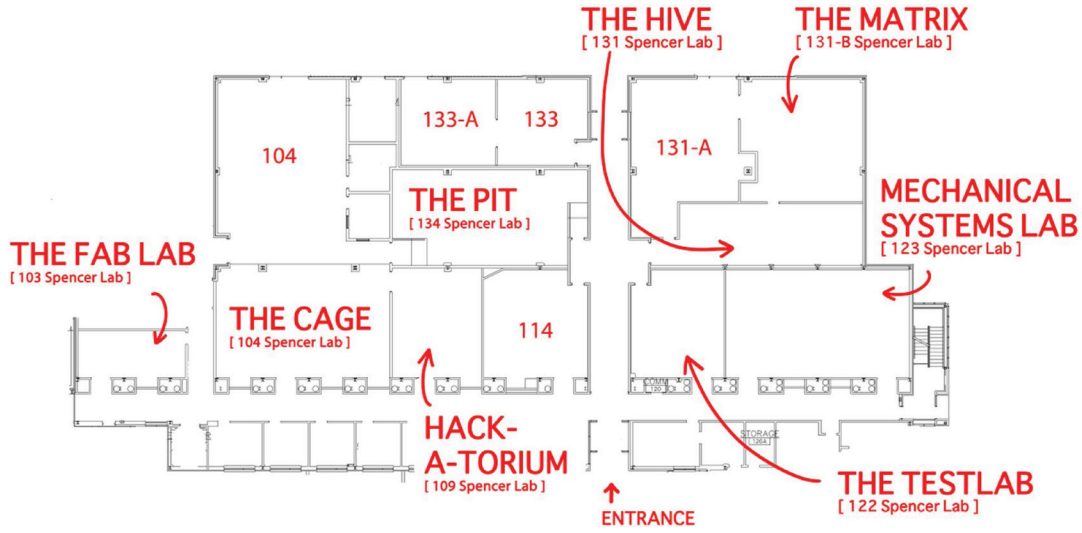

Figure 1. The current floor plan of the Design Studio. The student machine shop is located at the heart of the Design Studio in room 104 and extends into the area marked The Cage.

PHYSICAL SPACE, EQUIPMENT, AND RESOURCES

In its current state, the Design Studio encompasses a footprint of 5,500 square feet across nine interconnected rooms (**Figure 1**, **Figure 2**, and **Table 1**) on the ground floor of the core departmental building. The space and equipment continuously evolve to serve the needs of our students and department.

Table 1. Overview of room functions, major equipment, and access.

Room	Sq Ft	Access	Function/Equipment
103 (Club House)	350	24/7	Meeting space and storage for student clubs and organizations
104 (Machine Shop & Cage)	2,994	M-F 8-5	Mills, lathes, presses, table saw
109 (Fab Lab)	670	24/7	Digital Fabrication & Electronics: 3D Printers (Object, 3x Stratasys F170, ZMorph, MakerBot Replicator 2), Universal Laser cutter, vacuum former, Arduino kits, soldering stations
122 (Test Lab)		24/7	Measurement and sensing equipment, tension, compression, and fatigue test rigs
123 (Mechanical Systems Lab)	1,329	24/7	Undergraduate laboratory room
131 (Hive)	811	24/7	Collaboration and study space: computer cluster, white boards, tables
131-B (Matrix)		24/7	BSL-1 wet lab, biomedical lab support
133-A (Nook)		24/7	Group work, collaboration space, sink and mini-fridge
134 (Pit)	1,212	24/7	Wood shop: drills, dremels, belt sander, bandsaw, drill press, router, hand tools

Figure 2. The Fab Lab, one of several rooms in the Design Studio, houses the 3D printers, laser cutter, and electronics prototyping equipment.

Much of the larger equipment (laser cutter, 3D printers, etc.) was purchased in consultation with Amtek – a company that specializes in technical education equipment. This allowed us to leverage their experience with brand and model selection as well as consolidate maintenance and service contracts.

OPERATIONS

The day-to-day operation of the Design Studio evolved as the footprint and equipment portfolio of the makerspace expanded and student usage grew exponentially. At present, the Design Studio relies entirely on department funding for staffing, equipment maintenance, and material restock. No student fees are charged for equipment or material usage, even for extracurricular projects. Studio operating costs are on the order of $50k annually, with approximately 50% in restocking materials (e.g., wood, hardware, paint, 3D printing spools), 25% towards undergraduate intern support, and 25% towards routine equipment maintenance. These costs are offset for the department by corporate donations to our capstone design course as well as alumni donations towards studio operations and specific, smaller equipment purchases.

As indicated in the title, the Design Studio is primarily student run. While it is loosely managed by two faculty co-directors (the authors), a team of approximately 15 undergraduate TAs is paid hourly to perform most of the day-to-day work in the space. TAs are typically identified through an open application sent to all second and third year students, and they have also been hired ad-hoc when students were identified with necessary skills or expertise. At least one of the co-directors meets with the team of students weekly to discuss ongoing maintenance, space usage, upgrades, restock orders, and inefficiencies. There is continuous communication amongst the entire team, including faculty co-directors, through social media (GroupMe). TAs hold office hours in student workspaces during prototyping-intensive periods of each semester (typically last 3-4 weeks), and they otherwise complete daily or weekly tasks specific to their assigned role. Each of the TAs is assigned a specific role within the space that ranges from managing the 3D printing queue to general organization and restock, and these roles are detailed in a roles and responsibilities document that is reviewed with the TAs each semester. This allows us to be responsive, and immediately able to implement lessons learned from curricular engagement, events held in the space, etc. into our operating procedures.

Student staffing is reinforced by high-level support from the two faculty co-directors and departmental staff. The two faculty co-directors divide responsibilities for TA supervision, budgeting, and other operations concerns by work area, with one co-director (Roberts) responsible for digital manufacturing and electronics and the other (Buckley) covering light duty prototyping areas and testing equipment. The co-directors do not receive course-release for their service, but the department does provide supplemental salary and discretionary funding. Two full-time machinists maintain the student machine shop and coach students on mill, lathe, and welding work. A laboratory coordinator dedicates approximately 10% time towards safety compliance and facilities-related requests, and one staff administrator spends 5% time on procurement and budgeting.

Our policies and procedures related to student safety, equipment training, and access are continually evolving and, at present, are best described as a tiered system. All students in the department must take two in-person safety training sessions (basic shop safety and hand & power tools safety) and pass an online quiz with a score of 100% in order to access prototyping areas. Students may take this training at any time, but all are required to have completed training by their second semester in the program. Freshmen and sophomore year courses that utilize the Studio spaces then deliver just-in-time training on specific equipment. For example, a freshmen course teaches hand tools and power drill usage through an end-of-term project, and the sophomore-year design course uses dedicated lab time to teach students basic carpentry, 3D printing, laser cutting, and materials test machine skills. Safety, first aid, clean-up, and project storage are reinforced in all just-in-time trainings and monitored closely by the teaching assistants (TAs).

Access to the Design Studio is also tiered. All spaces except the student machine shop are open all-hours and accessible via card swipe tied to a student's university ID. Prior to implementing the

card swipe system, rooms were simply kept unlocked. To mitigate safety risk, some prototyping equipment is kept on lock-down unless a TA is present. Simple cord locks are used for this equipment, which include upright band saws, circular saws, large drill presses, and grinders. TAs have access to a lock box to unlock equipment, which is immediately locked down after lab sessions or TA office hours. The work queues for the 3D printers, laser cutter, and CNC router are managed directly by TAs, and students submit work requests and files through online portals (Google Forms). The student machine shop is open only during normal business hours (8 am to 5 pm) when one or more staff machinists are on hand to monitor usage and safety. Shop hours are extended during peak usage during heavy prototyping periods, again typically the final 3-4 weeks of each semester.

USAGE AND IMPACT

The resources and physical space of the Design Studio are used to support a wide range of curricular, extracurricular, research, and outreach activities (**Table 2**). The core function of the Design

Table 2. Courses and activities directly supported by the Design Studio (*Indicates courses that are physically held in the space).

Usage	User	Impact (#/year)
Curricular (required)	Introduction to Engineering	600 students
	Computer-Aided Engineering Design	160 students
	Machine Design – Kinematics and Kinetics	150 students
	Machine Design – Elements	150 students
	Senior Design	200 students
	*Vibration and Control	150 students
	*Fluids	150 students
	*Thermal Fluids	150 students
Curricular (elective)	*Prototype to Product	20 students
	*Applied Controls	20 students
	*Maker Series	40 students
Extracurricular	Student clubs and organizations	200 students
Research	Use of facilities by faculty and graduate and undergraduate research assistants	15 faculty 35 students
Outreach	Various professional development workshops and courses for K12 educators, summer camps for middle and high school students, visits from K12 students and clubs, etc.	15 UD students 70 teachers 150 K12 students

Studio is to support the undergraduate curriculum, including our underclassmen and capstone design courses, all laboratory-based courses, and demonstrations or hands-on learning sessions other courses. The majority (80%) of all core undergraduate courses and technical electives utilize the Design Studio's resources in some capacity, and several courses are held entirely in the space. Teaching assistants for all core courses are encouraged to hold office hours in the Design Studio study room (The Hive).

The Design Studio is used by several student organizations to design, build, and test their projects as well as hold events. These groups include student chapters of nationally recognized organizations (e.g. SAE, Engineers Without Borders (EWB), American Society of Mechanical Engineers (ASME), and the Biomedical Engineering Society (BMES)), as well as home-grown student organizations (e.g. two peer support organizations, multiple inventors clubs, a long-board production club, an assistive technology club, and a local non-profit organization involved in gender equity in STEM). These organizations actively share the workspace throughout the year, promoting an interdisciplinary and cross-curricular exchange of ideas throughout the four undergraduate years that students typically use the space.

During the off-terms (5 weeks in winter, 12 weeks in summer), the Design Studio is used for undergraduate student internships, K12 summer camps, and workshops for teachers in the local community. Every off-term, cohorts of approximately 10-15 students use the Studio for design-focused research or entrepreneurial projects with affiliated faculty. The Studio is also used, free-of-charge, by multiple K12 summer camps that attract 100-200 elementary, middle, and high school students. Other academic units, e.g., the College of Education or the Upward Bound Math and Science Program, typically administer these camps with Studio co-directors and/or TAs helping with curricular development and on-site support. The Studio also hosts multiple professional development (PD) workshops for K12 teachers, again supported by the co-directors and TAs. These include nationally recognized PD programs, such as Project Lead The Way, as well as custom-developed curriculum focused on pre-college engineering education. Approximately 60-80 K12 teachers are hosted in the studio for PD annually.

LESSONS LEARNED & PATH FORWARD

The Design Studio itself is a student-centered design project, and as such, it is inherently a work-in-progress. We are not prescribing that other institutions follow our exact pathway for development of their own academic makerspaces. However, we have some recommendations that others may find useful if faced with similar space, funding, or staffing constraints. Our lessons learned are summarized in **Table 3** below. Keeping the students (Minions) engaged in every decision about their space is a theme of our recommendations in every aspect.

Table 3. Lessons learned from the creation and operation of the Design Studio.

	Recommended	NOT Recommended
Physical Space	• Involve students in decisions about the function of a particular space as well as work flow • Build out rooms with simple fixtures that can be easily relocated as the space evolves • Take what you can get	• Believe that "if you build it, they will come" • Investing in expensive architectural features, fixtures, or furniture that make relocation or repurposing difficult
Equipment & Materials	• Provide open-access to tools and materials • Cluster equipment and materials by type of prototyping, e.g., electronics or carpentry • Use cord and cabinet locks as cheap and effective method to restrict student access within workrooms • Start with the basics (hand tools, drills, inexpensive 3D printer) then grow in response to student demand as funding allows (nicer 3D printers, laser cutter, etc.)	• Restrict access to entire work areas based on safety/usage restrictions of one machine • Cluster equipment by access level • Invest in expensive & time consuming access-management software until need is truly warranted
Staffing & Operations	• Recruit and continuously communicate with a core group of undergraduate TAs (Minions) to maintain, stock, and monitor work areas • Assign one or more Minions to major equipment (laser, 3D printers) for operation and maintenance • Appoint faculty director(s) who teach core undergraduate courses • Use administrative and technical staff mainly for high-level safety and budgetary oversight	• Rely on the undergraduate end-users to maintain and self-monitor the space • Appoint a full-time staff or faculty director with little connection to undergraduate student body

At present, the physical space and equipment within the Design Studio meet our community's needs and we are not actively planning further expansion within the next 1-2 years. Our short-term efforts focus on optimizing day-to-day operations, with an emphasis on safety, staffing, and inventory management. There are two objectives for long-term efforts: First, we are working to better support student entrepreneurs who utilize the Design Studio for their intra and extracurricular projects. According to the University of Delaware Policies and Procedures Manual [10], undergraduates own their own intellectual property. The authors are working with colleagues in business and entrepreneurship to develop curricula and programs for students interested in pursuing a myriad of commercialization pathways that range from open source licenses and trademarks to patents and formation of startups. The second long-term effort is to leverage our collective experience creating and operating the Design Studio to support nascent maker space efforts at our own institution.

Inspired in part by the Design Studio, the university has recently invested in a 6,000 square foot campus-wide space that is currently being designed to occupy an old gymnasium on campus. The

co-authors are involved as consultants on this project and have also been part of the effort to develop a campus-wide Maker Network to bring all the makerspaces on campus under one umbrella. This will help students (both current and existing) identify facilities on campus, make access to different spaces transparent, and facilitate resource sharing, service, and maintenance between all the spaces.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Dr. Suresh Advani, George W. Laird Professor and Chair of Mechanical Engineering, for the support of the work that led to this publication. We also thank Dr. Anette Karlson, now Dean of the Washkewicz College of Engineering at Cleveland State University, for her support in initiating the Design Studio project during her tenure as chairperson of the department. Institutional support for this project was provided by the University of Delaware's Mechanical Engineering Department, College of Engineering, and UniDel Foundation. And last, but certainly not least, we sincerely thank The Minions past and present who have contributed their time, energy, and financial resources towards to the Design Studio.

REFERENCES

[1] S. Doorley and S. Witthoft, *Make Space: How to Set the Stage for Creative Collaboration*, 1 edition. Wiley, 2011.

[2] J. S. Lamancusa, J. E. Jorgensen, and J. L. Zayas-Castro, "The learning factory - a new approach to integrating design and manufacturing into the engineering curriculum," *Journal of Engineering Education*, pp. 103–112, Apr. 1997.

[3] J. S. Lamancusa, J. L. Zayas, A. L. Soyster, L. Morell, and J. Jorgensen, "The Learning Factory: Industry-Partnered Active Learning," *Journal of Engineering Education*, vol. 97, no. 1, pp. 5–11, Jan. 2008.

[4] T. W. Simpson, E. Kisenwether, and G. R. Pierce, "Driving entrepreneurial innovation through the learning factory: The power of interdisciplinary capstone design projects," in *Proc. ASME Int. Design Engineering Technical Conf. and Computers and Information in Engineering Conf. (IDETC/CIE)*, Portland, OR, 2013, p. V001T04A009.

[5] V. Wilczynski, C. S. O'Hern, and E. R. Dufresne, "Using an engineering design center to infuse design experience into a mechanical engineering program," in *Proc. ASEE Annual Conference & Exposition*, Indianapolis, IN, 2014.

[6] C. R. Forest *et al.*, "The invention studio: A university maker space and culture," *Advances in Engineering Education*, vol. 4, no. 2, pp. 1–32, 2014.

[7] D. Roberts and J. Buckley, "The role of a design studio in a mechanical engineering department," in *Proc. American Society for Engineering Educators (ASEE) Annual Conference*, New Orleans, LA, 2016.

[8] D. Roberts and J. Buckley, "The role of a design studio in a mechanical engineering department," in *Proc. First International Symposium on Academic Makerspaces (ISAM)*, Boston, MA, 2016.

[9] D. Roberts and J. Buckley, "Case study: Maker space management by minions," presented at the VentureWell Open Conference, Washington, D.C., Mar-2017.

[10] "General Counsel | Intellectual Property Protection, Ownership, and Commercialization | University of Delaware."

AUTHORS

Dustyn Roberts i is a Philadelphia-based engineer, Senior Lecturer in the Mechanical Engineering and Applied Mechanics (MEAM) department within the School of Engineering and Applied Science (SEAS) at the University of Pennsylvania. She has taught courses that span the undergraduate curriculum on topics that range from first-year Intro to Engineering and Engineering Graphics to upper level hands-on labs and Senior Design. Her research in engineering education and entrepreneurship has attracted funding from organizations including NSF and VentureWell. Previously, she wrote "Making Things Move: DIY Mechanisms for Inventors, Hobbyists, and Artists" while in residence at Eyebeam Art & Technology Center, founded dustynrobots, LLC while consulting in NYC, and designed parts of robots that are now on Mars while at Honeybee Robotics. Dustyn holds a PhD in Mechanical Engineering from New York University, an MS in Biomechanics and Movement Science from the University of Delaware, and a BS with a double major in Mechanical & Biomedical Engineering (and minors in Robotics and Business) from Carnegie Mellon University. She is also a licensed professional engineer in New York (#087699) and Pennsylvania (#PE087240).

Jenni Buckley Jenni M. Buckley is an Associate Professor of Mechanical Engineering at University of Delaware (UD). She has over 10 years of engineering experience in medical device design and biomechanical evaluation and has research interests in human factors design, medical device development, and equity and inclusion issues in engineering education. She teaches a range of courses across the mechanical engineering curriculum, including CAD, mechanics, and capstone design; and she is the Co-Director of the UD Mechanical Engineering MakerSpace, The Design Studio. She is the Co-Founder and President of The Perry Initiative, a non-profit organization dedicated to diversifying the pipeline in engineering and medicine through hands-on learning. Dr. Buckley has received numerous awards for her teaching and service, including the 2016 University Excellence in Teaching Award, the 2016 Arthur A. Trabant Award for Women's Equity, and the 2018 American Society for Engineering Education "20 under 40" Engineering Educator Award.