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Using an Engineering Design Center to Infuse Design Experience into a Mechanical Engineering Program

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Abstract

Design and Innovation Centers are becoming popular creativity hubs on many engineering campuses. While a number of centers, such as Stanford University's d-school and Northwestern University's Segal Design Institute have existed for a long time, a significant number of other engineering centers have recently been established and even more are in the planning phase. These centers generally offer a location, infrastructure, and support for the university community to learn and work in a hands-on project-centered environment. Though each design center has a unique purpose relative to its home institution, the centers have all had a significant impact instilling design experiences into the campus culture. This paper examines the impact of the arrival of an engineering design center at one university and reports on how the impact has been documented. Through a single case study, the local results can serve as a template for new design centers to review as they plan and implement their own centers to foster design and innovation skills.

Introduction

A new phenomenon is in our midst: the rise of "academic maker spaces" on engineering campuses across the country. The phenomenon is so new that its arrival has yet to be characterized or defined with a proper title. This change to the engineering landscape manifests itself in the increasing number of institutions that have created new facilities to support student-focused design, innovation and invention interests on engineering campuses. Such spaces are given a variety of descriptive names such as design centers, innovation institutes, creativity labs, invention gymnasiums, and exploration studios. The range of activities suggested by such a collection of what is argued to be similar facilities complicates characterizing these spaces under a unifying title. Though some of the spaces are nearly a decade old, a recent increase in the number of such spaces on engineering campuses has resulted from greater awareness of the value of such spaces and the increased accessibility to the infrastructure (and its ease of use) that supports design and manufacturing activities.

A few examples illustrate the arrival of modern design centers on the engineering landscape. The non-descript label "design centers" is used in this paper to refer to such facilities which have a variety of descriptive names. Typically these new types of design spaces combine technology access with education in a format similar to community-based "makerspaces"[1]. Both the academic and community based versions of a makerspace generally include two components: the infrastructure and the community. The physical infrastructure includes equipment (such as tools, machine shops, electronic benches, design software and digital fabrication equipment) to design, prototype and test creative systems that solve problems. Equally important are the communities of users that tend to make use of these design spaces. They are generally individuals who are interested in not only their own ideas but also willing to help others realize their ideas. This peer-to-peer assistance is both formal and informal and takes the form of specific project consultation, instructional workshops on topics such as CAD and 3D printing, and lectures by professionals in the design community.

It is proposed that the most successful of these programs on college campuses include three components (where each campus program emphasizes the components that are most important in the local environment). Those three components are infrastructure that contributes to curricular efforts, support for extracurricular activities, and entrepreneurial assistance programs. In a way, these design centers combine the best features from, for example, MIT's Pappalardo Lab (which supports cornerstone and capstone design/build/test Mechanical Engineering courses), the student-run and open access MITERS workshop (which is dedicated to student organized projects, independent of the curriculum) and the numerous institute sponsored programs that foster student entrepreneurial activities (many of which fall under the umbrella of the MIT Industrial Liaison Program).

Stanford University's d-school is a ten-year old program that has served as a model for a number of the recently developed university design centers. The Stanford program is described as a hub for innovators at Stanford and encourages students and faculty from all disciplines to collaborate as they solve the world's most challenging problems. The d-school emphasizes learning by doing and stresses problem definition as a key step in solving real-world problems. Northwestern University's Segal Design Institute is another program with a long history of focusing on design thinking with multi-disciplinary teams. The institute provides instruction in human-centered design as well as access to fabrication equipment for hands-on interdisciplinary projects that involve undergraduate and graduate students.

A few of the more recent design centers that populate the university landscape include the Oshman Engineering Design Kitchen at Rice University. This facility has a structure similar to many other university design centers and includes a central work area, conference rooms, classroom, machine shop and rapid prototyping equipment. This center, which also includes a wet lab, was created to provide an environment where classroom knowledge could be combined with hands-on skills to create real-world applications. While some of the design centers are operated by the university and tend to have a curricular focus, others are operated by the students themselves and favor supporting student generated ideas. As an example, the Invention Studio at Georgia Tech is self-described as a "student-run design-build-play space open to all Georgia Tech students." Besides providing equipment, the studio is staffed to train students and help them with projects.

The Innovation Gymnasium at Southern Methodist University is geared to assisting small groups of students solve real-world problems within courses and in extracurricular activities. The SMU design center is also active in engineering outreach programs, another area that such facilities often contribute to. Other university design centers are still being planned and constructed. For example, Boston University's Engineering Product Innovation Center is being constructed as a teaching and design studio equipped with the latest manufacturing technology to prepare students in all aspects of product creation, manufacturing and deployment.

Many institutions showcase these design spaces in their external publications and often tout the space's availability to foster collaboration, innovation, creativity and invention. In essence the centers become a new method for infusing design skills into the engineering curriculum. Regarding the acquisition of design skills that are promoted by these spaces two questions are especially relevant:

1. What is the impact of a design center on a program's ability to deliver design education?
2. How is any impact on design education documented?

This paper presents a case study based on Yale's Center for Engineering Innovation and Design and explores local answers to these two questions.

Yale's Center for Engineering Innovation and Design

In 2009, the faculty at the Yale School of Engineering & Applied Science created a strategic plan for advancing the school, with one of three goals being to advance the culture of engineering on campus. Central to this goal was the creation of the Yale Center for Engineering Innovation and Design, an 8,500 square foot space for instruction and meeting, as well as equipment for fabricating and assembling engineered systems. The Center was created to support both curricular and extracurricular activities and is equipped with 3D printers, a laser cutting machine, a machine shop, fume hoods, a wet lab, and ample room to work on team-based projects.

Figures 1-5 illustrate the Center's teaching area, studio, rapid prototyping equipment, machine shop, and wet lab. The openness of the space and the connectedness between the Center's individual areas foster collaboration and the exchange of ideas between individuals, teams and projects that might otherwise not be associated with each other.

Figure 1. Teaching area in the Yale Center for Engineering Innovation and Design

Figure 2. Design studio with mobile work areas

Figure 3. Five rapid prototyping machines offer three methods of 3D printing

Figure 4. One of two machine shops that are components of the design center

Figure 5. Wet lab within the Yale Center for Engineering Innovation and Design

While the equipment and space are important, the programs and the supporting community are essential to the Center's ability to make an impact on campus by increasing the visibility of engineering, sparking creativity and accelerating collaboration. The Center hosts student design teams, academic courses and information workshops, as well as the modern tools and equipment to support these programs. The Center is open to all members of the Yale community that are interested in design and innovation. Its members range from theater majors that fabricate stage props to forestry students who construct equipment for scientific field work.

1,300 people became members of Yale's Center for Engineering Innovation and Design during the Center's first 18 months of operation. 65% of the membership is undergraduate students, with half of those students enrolled in STEM disciplines, 30% in Social Sciences, and 22% undeclared. It is noted that the far majority of the undeclared students are freshmen as Yale does not require students to declare their major during their freshman year. The remaining 35% of the members are from the Professional Schools (10%), graduate students in engineering and other disciplines (16%), and faculty and staff (9%).

The design center's membership structure establishes a sense of community, responsibility and ownership where members shape the values and norms of the space through their actions. Projects are pursued in the Center as personal interests, club activities, research quests and class components. Members who use the space benefit from an appropriate amount of staff oversight that provides design instruction, enforces safe practices, and ensures that projects conform to the Center’s norms.

A Design Center’s Contribution to Design Education

The design education program at the Yale School of Engineering & Applied Science has been advanced in five unique ways as a result of the Center’s arrival on campus. One of the most significant impacts has been the Center’s contribution to design skills associated with extracurricular activities. By showcasing the space and support available to support student designs, the number of student-generated design activities has significantly increased on campus.

The Center’s arrival on campus catalyzed growth in student organizations such as the local student chapter of Design for America and other similar hands-on student groups. In these cases, the teams use the Center as their common meeting space and make use of the facility for fabrication and construction. In addition, the Center support is also available for personal projects that students originate, such as the design of a musical instrument or fixing a broken mobile device. This increase in student design skills due to additional support for extracurricular activities provided by the design center is a very visible indicator of increased interest in design on campus.

Another area of local impact associated with the arrival of a design center on campus was increased levels of support for existing design-focused classes as well as the creation of new design-focused courses. The design center provided a single location for classroom instruction, meeting space and fabrication facilities that were critical for the Mechanical Engineering capstone design course as well as the course “Designing Appropriate Technologies for the Developing World.” In both of these courses, the teams’ ability to progress through the design process, fabricate components and assemble/test their designs was accelerated by working in a well-equipped and collaborative environment.

Since the opening of the design center, two new design-focused courses were added to the curriculum: a cornerstone course on engineering innovation and design and an upper level course on designing medical devices. Both classes included lectures, labs, and hands-on projects, with all of these activities taking place in the design center. The existence of the design center made these two courses possible as the Center provided a location where the instructor could easily (and often) transition from the lecture to hands-on examples to student-centered design activities. These examples illustrate the significant and immediate impact on the design experience within the engineering curriculum by supporting design-focused courses held in the design center.

Design education benefits also occurred in other non-design-focused courses such as statics and dynamics. To help infuse design experience into these fundamental engineering courses, design center staff developed a series of hands-on demonstrations and projects that connected the course’s theory to the real world. For example, an apparatus to visualize stress concentrations (using polarized filters) was designed and used by having the student compare the witnessed results to theoretical calculations. As another example, the vibration of laser-cut shapes was examined using modal analysis techniques, followed up by a project where students designed their own shapes that achieved a specified frequency response. This infusion of design principles into fundamental courses continues to be an important contribution that has been made possible by the existence of Yale's Center for Engineering Innovation and Design.

The existence of the design center has also accelerated student interest, and success in, entrepreneurial activities. While the university previously supported student entrepreneurship with a technology incubator program, the design center now allows students the chance to develop their prototype systems as working devices. For example, one student team developed a method to incentivize a scoliosis treatment procedure. That student group is now pursuing licensing the technology to a commercial firm. Another team of students were supported in the Center to develop a new method for cell phone communications, and that team is investigating licensing their technology. The arrival of Yale's Center for Engineering Innovation and Design has made these types of entrepreneurial activities more common place on campus.

The final example of the advancement of design skills that resulted in the opening of the Yale Center for Engineering Innovation and Design is the increased knowledge base of design skills that has resulted from formal and informal programs held in the Center. These programs have included student-led workshops on SolidWorks, microprocessors and 3D printing. The Center has also supported computer programming workshops where students teach fellow students. In addition to the proliferation of technical workshops that develop design skills, the Center provides a forum for lectures from the design industry leaders. While the university regularly hosted academic lectures, the number of lectures devoted to engineering design topics increased once the design center opened. The increase in design knowledge that has resulted from these workshops and lectures is significant.

These five examples of the resulting increase in design skills - facilitating extracurricular design activities, accelerating learning in design-focused courses, introducing design within fundamental courses, providing entrepreneurial support for design activities, and advancing design skills with workshops and design-lectures - illustrate the impact on design education that can result when design centers are added to a college campus.

Documenting the Impact on Design Skills

This section examines how the impact on design skills is captured and recorded. While the effectiveness of the design center itself can be quantified by metrics such as the number of members, member visits, workshops, and supported classes, measuring the impact of the design center on student design skills is a challenging problem.

It is noted that the media continues to show an interest in reporting design developments that result in university design centers as news items[2,3]. These reports provide an archived record of the anecdotal impact of specific design projects, thereby suggesting that university design centers may benefit from an aggressive program to inform local media of design efforts that impact the larger community.

Also of note are the active web portals that university design centers generally establish. These portals often present the center's activities in engaging fashions which rely on short headlines and rich images. While the presentation style is one to attract interest, an additional value of the web portals is their ability to document design related activities, including workshops, lectures, and conferences that originate from these centers. As such, the portals provide a record of activities that can be catalogued and archived.

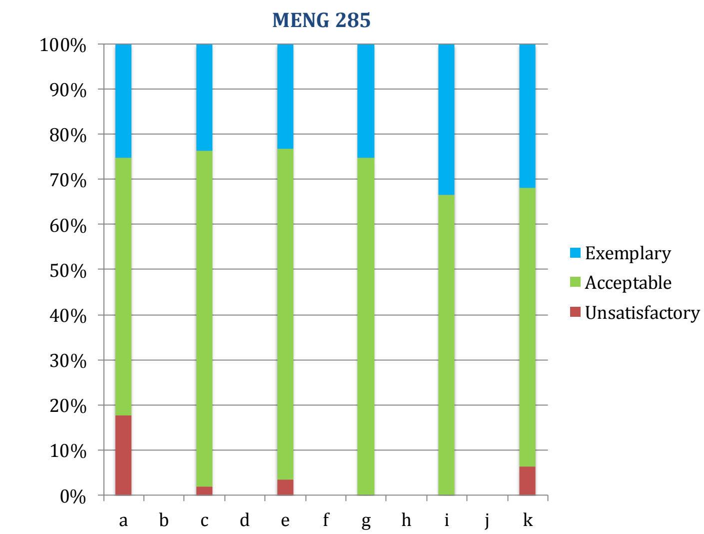
The design activities within design centers produce a number of design artifacts that can be saved or recorded to demonstrate the center's impact on design skills. Though such artifacts take up often limited space, they serve as a convenient method to illustrate how design principles were put into practice. Supporting documentation associated with such artifacts, including funding proposals for extracurricular projects or course reports from class projects, document the impact of design skills that result from work conducted in the design center.

Documentation methods used in conjunction with accreditation efforts can also be used as a tool for recording the impact on design skills associated with the creation of a design center. For example, in 2008 Yale's School of Engineering & Applied Science adopted an embedded assessment system to measure the attainment of Student Outcomes from each required course within the curriculum. This method was based on the call to create outcomes indicators and establish performance targets as well as the need to use direct assessment methods for accreditation purposes[4,5,6].

The locally developed method uses a spreadsheet (displayed in Appendix A) that identifies the contribution of course assignments and projects to fulfilling Student Outcomes. As a brief overview of this assessment monitoring process, the alignment of each course assignment (homework, projects, exams, etc.) with any relevant Student Outcomes is established at the beginning of the semester. The scores for the outcome-aligned assignments are then analyzed to determine the levels of performance for each Student Outcome achieved within that course. The data from all courses is then combined to measure the program's overall effectiveness achieving Student Outcomes.

The data from each course is summarized and tabulated as illustrated in Figure 6. The presented information identifies the percentage of students in that course that obtain distinct levels of performance (unsatisfactory, acceptable and exemplary) for each Student Outcome. Since all required courses in the curriculum use this analysis method, the aggregate data from all courses is combined to indicate the program's overall effectiveness achieving instructor assigned levels of performance, as illustrated in Figure 7.

Results: Course Summary



Outcome	Unsatisfactory	Acceptable	Exemplary	Total
a	18%	57%	25%	100%
b	0%	0%	0%	0%
c	2%	74%	24%	100%
d	0%	0%	0%	0%
e	4%	73%	23%	100%
f	0%	0%	0%	0%
g	0%	75%	25%	100%
h	0%	0%	0%	0%
i	0%	67%	33%	100%
j	0%	0%	0%	0%
k	7%	63%	33%	102%

Figure 6. Course level analysis of levels of performance achieved within each Student Outcome

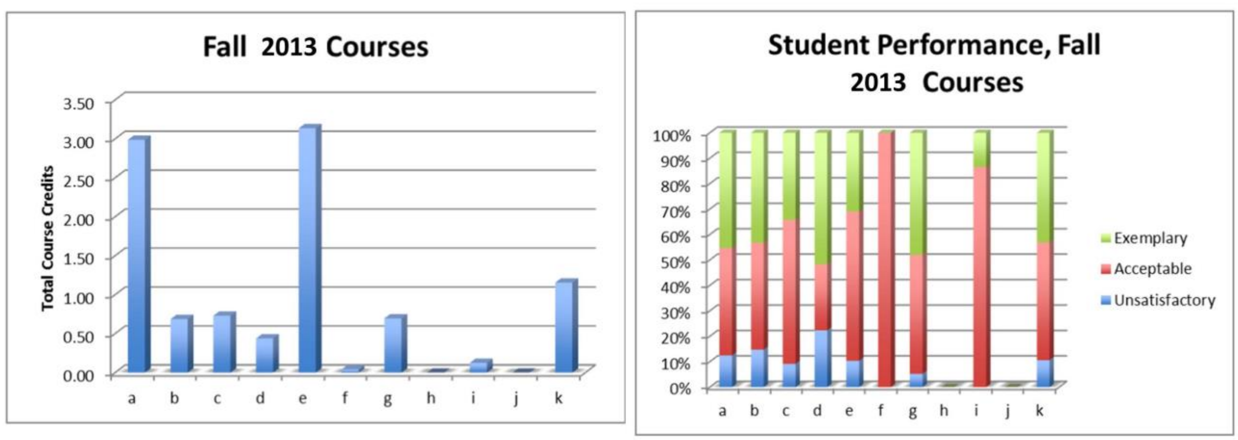


Figure 7. Program level analysis of coverage and levels of performance achieved for each Student Outcome

For the above examples, the achievement of design skills is reflected in the performance for Student Outcome (c) (design of a system, component, or process) and perhaps Student Outcome (k) (use of modern engineering tools). Since this information has been collected before and after the arrival of the design center at Yale, the information will be reviewed to see the changes that resulted in these two outcomes for courses that are supported by the design center. These quantitative results, combined with the artifacts of the design processes detailed above, can demonstrate the level of design skills that is facilitated by the presence of properly staffed and well outfitted design centers. This information is currently being collected and analyzed during the present academic year and will be reported in the Department's ABET Self Study.

Observations

The accessibility and availability of digital fabrication methods, a rising interest in creating physical objects and a growing realization of the importance of design skills has fueled the development of design centers on college campuses. These centers have been established to accommodate student interest in the creation, construction and testing of engineered systems.

University design centers promote hands-on, community-supported learning, and mimic the non-academic versions of such facilities that are referred to as makerspaces[6]. These spaces have been shown to increase design skills by providing access to technology and training. In addition, the communities of fellow users of such spaces have a culture of collaboration that enhances peer to peer learning.

Within the academic community, the arrival of design centers on campus has benefitted the attainment of design skills as a result of contributions within the curriculum and through the support of extracurricular activities. The design centers focus on hands-on, project-based learning, often with students working in teams. Such approaches have been shown to be very effective in accelerating the abilities of individuals to apply theory to solve real world problems.

There are a number of best practices that can be shared with institutions that are considering a design center. That list should include engaging students, faculty and staff in all aspects of planning, design, outfitting, and commissioning the space. Design centers should be established as university resources, similar to the role of a campus library, and not as school or departmental facilities. The broad user base that results from being a university resource (in that the users of the space originate from all disciplines) will enhance a design center's ability to attract a wide and diverse membership. This diversity of members will enhance the success of individual projects and the overall success of the center. Much remains to be documented and shared regarding university design centers and the authors are in the process of such work.

Standard Student Outcomes assessment methods (commonly used as the baseline for continuous improvement systems) have the potential to record the impact of design centers on developing design skills. Since these methods are longitudinal in nature, they provide a perspective to examine the before and after effects of the establishment of design centers on college campuses.

The establishment of design centers on college campuses is not a new phenomenon, but advancements that have increased the accessibility to design tools and methods are making the presence of such centers possible on a larger number of college campuses. With the proper amount of institutional and peer-based support, they have the potential to dramatically strengthen design skills for a large number of students.

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Appendix A: “The Yale Method” for Assessing Student Outcomes Spreadsheet for Recording Course Level Input

YALE SCHOOL OF ENGINEERING AND APPLIED SCIENCE

MECHANICAL ENGINEERING ABET OUTCOME REVIEW

This spread sheet template tracks achievement of the ABET Student Outcomes.
To use this spreadsheet, fill out the parts in green - everything else should take care of itself.

ABET Student Outcomes:
(a) apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) design a system, component, or process to meet desired goals
(d) an ability to function on a multi-disciplinary team
(e) identify, formulate, and solve engineering problems
(f) understand professional and ethical responsibility
(g) communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) recognize the need for life-long learning
(j) a knowledge of contemporary issues
(k) use modem engineering tools necessary for engineering practice

Course Number:	MENG-123
Course Name:	

To use this spreadsheet, fill out the parts in green - everything else should take care of itself.

The grade sheet uses faculty assigned weighting factors for each test and homework assignment. The maximum possible points is the weighting factor * 100.

		HW1	HW2	HW3	HW4	HW5	HW6	HW7	HW8	HW9	HW10	HW11	FINAL EXAM		
ABET Student (Yes/No)	Student Name	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [150]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	FINAL EXAM [300]	Assigned Grade	Overall Percent
		92	93	98	93	90	90	89	130	92	88	87	275		91%
		92	86	88	90	40	80	0	0	94	0	70	240		61%
		100	94	100	98	90	98	81	130	95	90	95	280		93%
		92	88	94	93	97	95	93	130	94	90	95	285		93%
		90	95	97	94	90	95	93	134	95	92	94	282		93%
		100	95	90	86	0	93	94	120	90	0	92	275		78%
		92	86	85	88	95	88	90	135	92	93	85	261		89%
		83	80	86	93	91	88	90	130	93	95	87	265		88%
		95	90	100	98	0	88	90	137	95	100	96	295		89%
		100	96	90	91	90	92	78	135	93	90	90	270		91%
		80	94	98	97	0	94	98	145	93	100	95	282		88%
		100	95	100	98	91	97	94	135	93	100	100	288		96%
	weighting factor	1	1	1	1	1	1.0	1	1.5	1.0	1.0	1.00	3.0		

Please assign a fraction of a-k to each assignment. Since there are weekly assignments, it is not necessary to break things down to the level of individual problems. If there were only a midterm and a final, that might be appropriate.
Please scroll right to view the table in its entirety.

ABET Outcome	HW1	HW2	HW3	HW4	HW5	HW6	HW7	HW8	HW9	HW10	HW11	FINAL EXAM	Percent of Course
a					0.5		0.5				0.75		12.1%
b													0.0%
c		0.5				0.5		0.5	0.5			0.2	19.7%
d													0.0%
e				0.5			0.5					0.4	15.2%
f													0.0%
g									0.5			0.2	7.6%
h													0.0%
i						0.5							3.4%
j													0.0%
k	1	0.5	1	0.5	0.5			0.5		1	0.25	0.2	42.1%
(should sum to 1)	1	1	1	1	1	1	1	1	1	1	1	1	100%

This last column shows how much of the a-k goes into the course grade. This will be useful information for evaluating our program.

Please enter performance cutoff percentages below. These are the numbers that determine the cutoff between Unsatisfactory, Acceptable, and Exemplary.

Cutoff Percentages	
80	Unsatisfactory
95	Exemplary

Breakdown of Student Performance by Assignment

*Each column should add up to the number of students in the course.

	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [150]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	Descriptive Title of HW [100]	FINAL EXAM [300]
Unsatisfactory	0	0	0	0	4	0	2	1	0	2	1	0
Acceptable	7	8	6	8	6	8	9	10	9	6	6	9
Exemplary	5	4	6	4	2	4	1	1	3	4	5	3

Figure A-1. The common spreadsheet used to collect data for measuring the attainment of Student Outcomes