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Assessing the Value and Implementation of Interdisciplinary Activities in Academic Makerspaces and Machine Shops

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Caroline Benish

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Introduction

This paper first investigates the value that engineering companies place on (1) interdisciplinary experiences and (2) hands-on skills learned in university makerspaces and machine shops. A survey was completed by 259 company representatives at the University of Wisconsin College of Engineering (UW CoE) career fair and over 90% said that interdisciplinary experiences are valuable to their company and they would be more likely to hire an engineering student with them. Certain hands-on skills such as 3D printing were considered valuable, though they did not score as high as interdisciplinary experiences. Thus, to provide more value to students, makerspaces and machine shops could be used to provide both hands-on skills *and* interdisciplinary experiences.

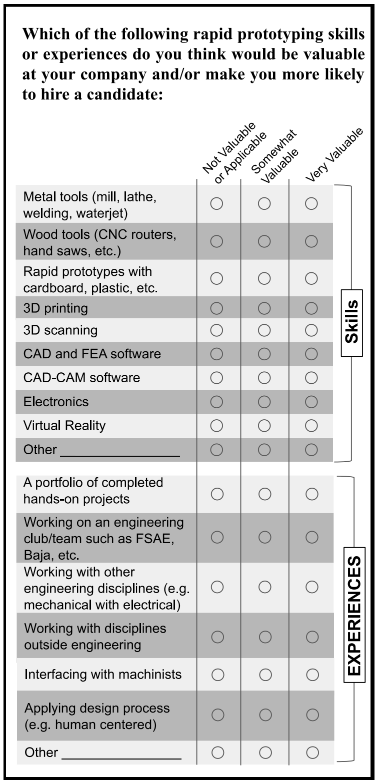
Secondly, this paper explores how the UW CoE fostered interdisciplinary activities through their makerspace and machine shop by offering targeted courses, workshops and programs. The overall aim was to create an academic pathway of interdisciplinary experiences for engineering students from pre-college programs through a master's degree. Data was used to quantify the amount of interdisciplinary activity, which showed that 85% of the 1600 makerspace workshop attendees were there to gain skills *outside* their disciplines. This indicates that a makerspace may be well suited to foster interdisciplinary activities.

Background

To study interdisciplinary experiences, we must first define interdisciplinarity in the context of engineering education. Interdisciplinary activities bring together students with "heterogeneous knowledge bases and knowledge-making practices" [1]. In response to the growing complexity of real-world engineering problems [2], universities create opportunities for students to work on real-world problems in interdisciplinary teams to better prepare graduates for these new demands [3]. Interdisciplinarity enables students to bring their own expertise and unique approach to problem-solving to a diverse group. Collectively the group aims to solve more complex problems and/or find unique solutions. The topic of Collective Intelligence and how it applies to interdisciplinary engineering groups is a related topic though left for future discussions [4].

Assessing the value of interdisciplinary experiences

A survey was distributed to company representatives that were attending the Fall 2018 UW CoE career fair. The survey asked "Which of the following rapid prototyping skills or experiences do you think would be valuable at your company and/or make you more likely to hire a candidate?" Underneath was a list of hands-on skills and experiences that engineering students could obtain while working in a makerspace and/or machine shop (Figure 1). For each item, the respondent indicated if the particular skill or experience was either Not Valuable, Somewhat Valuable or Very Valuable. 259 company representatives completed the paper survey over the three-day career fair.



Which of the following rapid prototyping skills or experiences do you think would be valuable at your company and/or make you more likely to hire a candidate:

	Not Valuable or Applicable	Somewhat Valuable	Very Valuable	
Metal tools (mill, lathe, welding, waterjet)	○	○	○	Skills
Wood tools (CNC routers, hand saws, etc.)	○	○	○	
Rapid prototypes with cardboard, plastic, etc.	○	○	○	
3D printing	○	○	○	
3D scanning	○	○	○	
CAD and FEA software	○	○	○	
CAD-CAM software	○	○	○	
Electronics	○	○	○	
Virtual Reality	○	○	○	
Other _______________	○	○	○	
A portfolio of completed hands-on projects	○	○	○	EXPERIENCES
Working on an engineering club/team such as FSAE, Baja, etc.	○	○	○	
Working with other engineering disciplines (e.g. mechanical with electrical)	○	○	○	
Working with disciplines outside engineering	○	○	○	
Interfacing with machinists	○	○	○	
Applying design process (e.g. human centered)	○	○	○	
Other _______________	○	○	○	

Figure 1: The paper survey used at the engineering career fair to investigate the value engineering companies place on (1) hands-on *skills* learned in makerspaces and machine shops, and (2) interdisciplinary *experiences*.

DATA ANALYSIS

The results of the survey are shown in Table 1. For example, 44% of those surveyed said that engineering candidates with metal tool skills are not valuable or applicable while 18% of those surveyed said that skills with metal tools are "Very Valuable." Table 2 shows the percentage of respondents that considered a particular skill or experience somewhat *or* very valuable, sorted from highest to lowest value. A composite score was also calculated by giving "Very Valuable" responses one point, "Somewhat Valuable" 0.5 points and "Not Valuable or Applicable" zero points. The sum of these points equaled the composite score, which has a range from 0 to 259.

A. RESULTS AND DISCUSSION

Observation #1: Table 2 shows that the respondents highly value interdisciplinary experiences, which are highlighted in grey, over the specific hands-on skills. One explanation could be that there was a wide range of engineering professions and interests represented in the population of respondents; While a specific hands-on skill such as 3D printing may be very valuable in a specific field such as consumer product development, it may not be valuable in all engineering professions. Interdisciplinary experiences, however, seem applicable and valued across multiple engineering fields.

Table 1. The results in the order the questions were listed on the survey.

	Not Valuable or Applicable (%)	Somewhat Valuable (%)	Very Valuable (%)
Metal tools (mill, lathe, welding, waterjet)	44	38	18
Wood tools (CNC routers, hand saws, etc.)	68	27	5
Rapid prototypes with cardboard, plastic, etc.	49	32	19
3D printing	37	34	29
3D scanning	41	36	23
CAD and FEA software	16	19	66
CAD-CAM	20	31	50
Electronics	17	33	50
Virtual Reality	55	32	12
A portfolio of hands-on projects that they've completed individually or with teams	14	30	56
Working on an engineering club/team such as FSAE, Baja, etc.	10	39	51
Working with other engineering disciplines (e.g. mechanical with electrical)	7	27	66
Working with disciplines outside engineering (i.e. interdisciplinary experience)	9	42	49
Interfacing with machinists	33	36	31
Applying design process (e.g. human centered or other)	10	33	56

Observation #2: Virtual Reality (VR), which is a relatively new technology, was not considered valuable by over half of the respondents. A possible explanation could be that it is too early for companies to fully understand where VR could be utilized in their organization. In other words, it could be similar to asking companies about 3D printing in the early 1990s when the technology was too new to be fully used in engineering.

Observation #3: Wood tools were ranked the lowest. A possible explanation could be that wood tools are associated with traditional, craftsmanship-based approaches instead of highly engineered, high-tech approaches. However, there are many computer-based tools that can use wood as an effective material for rapid prototypes (e.g. laser cutter, CNC routers), though some of the representatives surveyed may not have been familiar with these tools and approaches.

Table 2. The survey results ranked from highest to lowest composite score. A composite score was also calculated by giving "Very Valuable" responses one point, "Somewhat Valuable" 0.5 points and "Not Valuable or Applicable" zero points. The sum of these points equaled the composite score, which has a range from 0 to 259.

	Respondents that indicated value (%)	Composite Score
Working with other engineering disciplines (e.g. mechanical with electrical)	93	207
Working with disciplines outside engineering (i.e. interdisciplinary experience)	91	182
Working on an engineering club/team such as FSAE, Baja, etc.	90	182
Applying design process (e.g. human centered or other)	90	189
A portfolio of hands-on projects that they've completed individually or with teams	86	185
CAD and FEA software	84	194
Electronics	83	172
CAD-CAM	80	169
Interfacing with machinists	67	127
3D printing	63	119
3D scanning	59	107
Metal tools (mill, lathe, welding, waterjet)	56	95
Rapid prototypes with cardboard, plastic, etc.	51	91
Virtual Reality	45	74
Wood tools (CNC routers, hand saws, etc.)	32	49

Ways to foster Interdisciplinary opportunities

As discussed in the previous sections, interdisciplinary experiences are valued by the companies surveyed. A logical question could be "how might an engineering university foster interdisciplinary activity through a makerspace and/or machine shop?" To address this question, this section provides a summary of the approach taken by the makerspace and machine shop at UW CoE to provide interdisciplinary opportunities for their engineering students. The overall aim has been to provide an academic pathway for interdisciplinary design starting in pre-college and going through a master's degree (Figure 2).

Figure 2: The UW CoE makerspace and machine shop helps create an academic pathway for students interested in interdisciplinary design and innovation by supporting a wide range of programs, courses and organizations. The above arrow shows an interdisciplinary path a student could take starting in pre-college programs and going all the way through a master's degree.

A. PRE-COLLEGE PROGRAMS

Each summer the makerspace hosts the Engineering Summer Program [5] and a set of programs offered through the Wisconsin Center for Academically Talented Youth [6]. Though these programs, high school students are exposed to the STEM fields through hands-on, interdisciplinary, design projects.

B. FIRST-YEAR INTEREST GROUPS

First-Year Interest Groups (FIGs) are clusters of three UW CoE classes, linked together to explore a common theme, and offered to incoming freshmen who attend these classes together as a cohort [7]. During the fall of 2018, the makerspace hosted an interdisciplinary FIG between the School of Human Ecology and the College of Engineering. The "making" theme of the FIG involved 40 students from across campus working with the UW CoE Child Development Lab to prototype devices that helped preschool kids learn outdoors [8].

C. STUDENT ORGANIZATIONS AND EVENTS

Both the machine shop and makerspace support over 15 student organizations (clubs, teams) that design and build prototypes as part of their mission [9]. The student organizations have members from across the College of Engineering and thus offer an interdisciplinary experience for students. Also, the makerspace has held "hackathons" and "makeathons" that are open to students from across the university.

D. CERTIFICATE PROGRAM

UW CoE allows students to add additional specialization to their major through the Certificate Program [10]. Similar to what other universities often call a "minor" degree, the Certificate often requires students to take an additional set of courses. The makerspace is supporting a new "Design Thinking" Certificate that will be added by Fall 2021, which will offer students with interdisciplinary experiences through a set of design courses.

E. CAPSTONE DESIGN COURSES

As of the 2018-19 academic year, each engineering department runs their own capstone course with students primarily from their own department. Starting in Fall 2019, however, the machine shop and makerspace will host 3 interdisciplinary capstone projects where students from mechanical and electrical engineering will work together.

F. MASTERS DEGREE PROGRAM

Starting in Summer 2020, the makerspace and machine shop will host a new 1-year interdisciplinary master's degree between the College of Engineering, School of Business, the Art Department, the Information School and the School of Human Ecology. This program will teach students to work on interdisciplinary teams to create products and/or services that address a market need.

G. STUDENT STAFF

The makerspace and machine shop are run by approximately 55 student staff, which maintain the equipment and provide technical support to users. Hiring a diverse set of student staff can foster an interdisciplinary environment, and thus the student staff have majors from across the College of Engineering, the Art Department and the School of Business.

Analyzing the interdisciplinary activity at the UW CoE makerspace and machine shop

This section presents a more quantitative approach to assess the interdisciplinary activity at the UW CoE makerspace and machine shop through the following categories:

- **Community:** Were the users of the makerspace and machine shop from a wide range of departments?
- **Learning:** Did the makerspace workshops enable users to pursue skills outside their discipline?

If the above questions are true, then the makerspace and/or the machine shop could be considered successful in fostering an interdisciplinary environment.

A. COMMUNITY

The home department of users entering the makerspace and machine shop were tabulated for the 2018-19 academic year using Dataset B (Appendix B). Table 3 lists both the total number (No.) and percentage (%) of users entering from each department category. For example, there were 3673 users from the Mechanical Engineering department entering the makerspace, which was 19% of the total number of users entering the makerspace. Table 4 summarizes whether the user was from the College of Engineering. The following conclusions can be made based on these two tables:

- 60% of the machine shop users were from only two engineering departments (mechanical engineering and biomedical engineering).

- The makerspace had more users from other departments such as electrical engineering and computer science though the data shows a clear need to diversify even more.
- The makerspace had 19% of their users from outside engineering while the machine shop only had 2%.

Table 3. The home department of users entering the makerspace and machine shop during the 2018-19 academic year using Dataset B.

	Makerspace		**Machine Shop**	
	(No.)	(%)	(No.)	(%)
Mechanical Engineering	3673	19.0	5398	33.2
Biomedical Engineering	3649	18.9	4431	27.2
Engineering Mechanics	826	4.3	808	5.0
Civil Engineering	761	3.9	1152	7.1
Electrical & Computer Engineering	3886	20.1	637	3.9
Computer Science	1290	6.7	60	0.4
Other	5213	27.0	3785	23.3
Total	19298	100.0	16271	100.0

Table 4. The home department of users entering the makerspace and machine shop during the 2018-19 academic year using Dataset B.

	Makerspace		**Machine Shop**	
	No.	%	No.	%
Engineering	15612	81	15981	98
Non-Engineering	3686	19	290	2

B. LEARNING

The amount of interdisciplinary learning was explored using Dataset C (Appendix B) and the “Interdisciplinary Matrix” described below [11]. This matrix can be used to explore the questions: Did the workshops enable users to pursue skills outside their discipline? Or how effective was the makerspace at breaking down departmental siloes? Each of the 145 workshops offered during the 2018 academic year were categorized as being mechanical (Mech), electrical (Elect), biomedical (Bio), other engineering (Other-Engr), computer science (C.S.) or other non-engineering (Other Non-Engr). As an example, a workshop on the topic of Virtual Reality was categorized as “C.S.” and craft workshops such as making a Laser-cut 3D Holiday Cards was categorized as “Other Non-Engr.”

Let us define a matrix A and call it the Interdisciplinary Matrix, where the rows represent the category of workshop described above and the columns represent the home department[1] of the workshop attendees (Figure 3). Note that the same groupings were used for home department (i.e. "Mech" means the workshop attendee was from the mechanical engineering department). The value in each matrix cell represents the fraction of participants from a particular department grouping that attended a workshop of a particular category (e.g. a value of 0.2 in cell A(1,2) would mean that 20% of the participants that attended the mechanical-oriented workshops were from the electrical engineering department).

If the makerspace was completely siloed, ***A*** would have only 1's down the diagonal (i.e. only those from mechanical engineering attended mechanical-oriented workshops, only those from electrical engineering attended electrical-oriented workshops, etc.). While large off-diagonal values would indicate more interdisciplinary activity. The amount of interdisciplinary activity can be quantified by calculating the average off-diagonal values in each row:

$$I_a = \frac{1}{n}\sum_{i=1}^{n}(1 - A_{ii}) \tag{1}$$

Where n is the number of rows and columns in the Interdisciplinary Matrix ($\boldsymbol{A}$). The value of I_a ranges from 0 to 1, which indicates the amount of interdisciplinary activity from lowest to highest, respectively.

Figure 3 shows the calculated values for the Interdisciplinary Matrix using the workshop data. The zeros in the matrix indicate the need for more workshops outside the mechanical and electrical categories (e.g. more Biomedical, Nuclear or Civil Engineering topics). Finally, I_a was found to be 0.85 for the 145 workshops offered in the 2018-19 academic year. This means that on average, 85% of the users in each workshop category were pursuing skills outside their discipline. Note that the "Bio" and "Other Engr" categories were not included in the calculation since the all-zero rows would yield erroneous results.

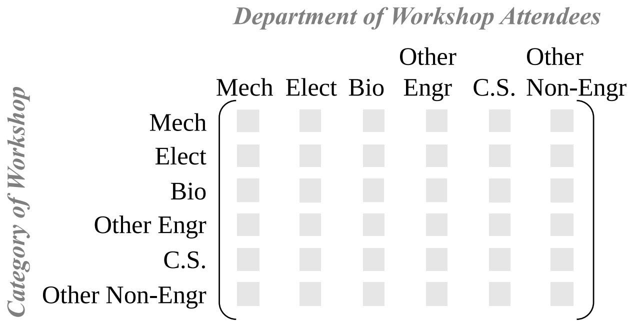


Figure 3: The Interdisciplinary Matrix (A) was created to quantify interdisciplinary activity.

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[1] The UW CoE CoE departments: Biomedical Engineering, Chemical and Biological Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, Engineering Physics, Materials Science and Engineering, Mechanical Engineering and Biological Systems Engineering.

Department of Workshop Attendees

Category of Workshop

$$\begin{array}{r|cccccc|}
 & \text{Mech} & \text{Elect} & \text{Bio} & \text{Other Engr} & \text{C.S.} & \text{Other Non-Engr} \\
\text{Mech} & 0.29 & 0.06 & 0.27 & 0.30 & 0.01 & 0.06 \\
\text{Elect} & 0.15 & 0.15 & 0.30 & 0.27 & 0.06 & 0.07 \\
\text{Bio} & 0 & 0 & 0 & 0 & 0 & 0 \\
\text{Other Engr} & 0 & 0 & 0 & 0 & 0 & 0 \\
\text{C.S.} & 0.14 & 0.06 & 0.39 & 0.35 & 0 & 0.07 \\
\text{Other Non-Engr} & 0.18 & 0.08 & 0.28 & 0.30 & 0.03 & 0.14
\end{array}$$

Figure 4: The "Interdisciplinary Matrix" was calculated using Dataset C. The value in each matrix cell represents the fraction of participants from a particular department grouping that attended a workshop of a particular category.

Conclusions

Question #1: Are hands-on skills and interdisciplinary experiences considered valuable to engineering companies?

Conclusions: Over 90% of the company representatives surveyed said that interdisciplinary experiences are valuable to their company and would be more likely to hire an engineering student with them. Certain hands-on skills such as 3D printing were considered valuable, though they did not score as high as interdisciplinary experiences. This may be because hands-on skills such as 3D printing are often specific to a certain discipline (e.g. mechanical engineering), while interdisciplinary experiences apply across all engineering disciplines. Thus, to add more value to students, a makerspace should be used to provide not just hands-on skills but also interdisciplinary experiences.

Question #2: How did the UW CoE’s makerspace and machine shop provide interdisciplinary opportunities?

Conclusions: The UW CoE makerspace and machine shop provided a wide range of interdisciplinary opportunities for students through courses, workshops and programs. The overall aim is to create an academic pathway for students starting in pre-college and going all the way through a master’s degree.

Question #3: Were the makerspace and machine shop at UW CoE able to create interdisciplinary activity?

Conclusions: 60% of the machine shop users were from the mechanical engineering and biomedical engineering departments and thus could be considered less interdisciplinary. The makerspace had more users from other departments such as electrical engineering and computer science though still needs to increase the number of users from other departments. The

Makerspace had 19% of their users from outside engineering while the machine shop only had 2%. This may be due to policies that limit access to the machine shop for those outside engineering. Finally, the Interdisciplinary Matrix was derived and showed that 85% of the users attending the makerspace workshops were there to gain skills outside their disciplines. Thus, workshops were a good approach to fostering interdisciplinary activity.

Future Research

First-year engineering students pose both an interesting problem and opportunity for creating the interdisciplinary experiences previously defined. First-year students have not had sufficient disciplinary experience and training to be able to serve as disciplinary experts in a diverse team. However, this creates an opportunity to teach these students the skills required to be effective in interdisciplinary teams early on in their academic careers. This leads to a number of questions worth investigating: 1) Can we identify these skills? 2) Can we develop a curriculum/integrate training into the existing curriculum to train these skills? 3) Can we measure the effectiveness of this new training? Do the students trained in these newly identified skills exhibit improved interdisciplinary teamwork as upperclassmen?

Improving a student's ability to communicate effectively, prototype solutions, and learn from teammates have been identified as potential ways to enhance interdisciplinary teams' performance [12] and offer a framework on which to base our answer to Question #1. We suspect that learning to become a disciplinary ambassador, as much as disciplinary skill- and knowledge-building, is a critical component of learning to be an effective interdisciplinary team member. Rather than solely focusing on final-year capstone experiences for interdisciplinary experiences, we believe there is untapped potential in focusing on first-year students and their multi-year development into effective interdisciplinary teammates. There is also interesting work to be done with looking at how a team's Collective Intelligence is impacted by interdisciplinary teams [4] and how a curriculum could be setup to teach interdisciplinary tools as part of the design process.

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Appendix A: Design and Fabrication Facilities

The UW CoE has had a centralized machine shop since the early 1990s [13]. In the fall of 2017 a makerspace was added as a separate but nearby facility [14] [15]. These two complementary facilities form the CoE Design and Fabrication Labs. The mission of the Design and Fabrication Labs is to foster:

- **Hands-on Learning:** Bridging the gap between theory and application.
- **Student Empowerment:** Empowering students to design and build on their own initiative.
- **A Diverse Community:** A welcoming community that enables collaborations that are diverse in terms of gender, race and discipline.
- **Peer Learning:** Students teaching and learning from other students.
- **Product Design:** A hub for inventing and designing new products.
- **Open Access to Technology:** Offering an expansive library of technology, equipment and tools.

The labs teach primarily engineering students, faculty and staff to fabricate items for courses, research, student clubs and personal projects. Below is an overview of the machine shop and makerspace (Table 5).

Table 5: The amount of staff and floor space of the machine shop and makerspace. Each student staff member works approximately 10 hours per week.

	Full-time Staff	**Student Staff**	**Floor Size (m^2)**
Machine shop	9	38	1k
Makerspace	3	30	1.2k

C. MACHINE SHOP

The machine shop has both metal working equipment (e.g. mill, lathe, welding, sheet metal) and wood working equipment (e.g. saws, sanders, planer). It also runs the shop training program and offers fee-based design and fabrication services. The maintenance and operation of the equipment are managed by full-time staff with support from part-time student staff.

D. MAKERSPACE

The makerspace is a rapid prototyping facility that includes tools and software for 3D printing, 3D scanning, virtual reality, robotics, data visualization, electronics fabrication, laser cutting, CNC-routing, textiles and thermoforming. The maintenance and operation of the equipment is managed by student staff with support from full-time staff.

E. FORMAL TRAINING (PERMITS AND UPGRADES)

Formal training is defined as instruction offered mainly by full-time staff with the objective of granting access to specific pieces of equipment. The machine shop and makerspace use a common formal training program consisting of permits and upgrades [11].

F. INFORMAL TRAINING (WORKSHOPS)

Informal training is defined as instruction offered mainly by student staff that is typically based on a topic of interest and not a mandatory pathway to equipment access (e.g. a workshop on

"Sensors for the Human Body." The makerspace offered informal training through 170 workshops in the 2018-19 academic year, which were mainly developed and taught by student staff. The workshops were typically held in the evenings for 1 to 2 hours and an opportunity for students to have hands-on, peer-based instruction on topics both inside and outside their home department. The workshops were open to all students, faculty and staff at UW CoE including those outside the College of Engineering.

Appendix B: Datasets

Three data sets were analyzed in this paper:

- **Dataset A:** A survey handed out to company representatives attending the fall 2018 UW CoE College of Engineering (CoE) career fair. The survey was intended to assess the value of hands-on skills and interdisciplinary experiences.
- **Dataset B:** The home department of the users of the CoE's makerspace and machine shop were logged when they swiped their university identification card (ID) upon entering the labs.
- **Dataset C:** The home department of each workshop attendee was collected using an iPad. See previous section *F. Informal training (Workshops).*

For all of the statistical analyses, a hypothesis test for the difference of two proportions was used with a p-value cut-off of 0.05 [16].

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