INCORPORATING A COMMUNITY-BASED RAPID MANUFACTURING FACILITY INTO A FIRST YEAR ENGINEERING DESIGN COURSE

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Abstract – University engineering departments are often challenged to maintain state of the art manufacturing facilities due to the rapid technological changes that are occurring in industry. Older or obsolete engineering laboratory equipment, manufacturing machines, and design tools are difficult to replace due to limited department budgets, space, and staff resources. At Capilano University, where a hands-on project-based one semester first year engineering design class is offered, the Engineering department has taken a novel approach to meet the above challenge.

The Engineering Design students are required to design, build, and test original prototype electrical circuits, and mechanical structures as part of their design projects. Construction of these student-designed units requires a rapid turnaround manufacturing facility to meet the peak demands of the students, capabilities that smaller universities are often limited in their ability to provide.

To meet this specific requirement, a community-based private rapid prototyping design and manufacturing facility, Zen Maker Labs, was approached, and a partnership agreement has been developed. The agreement consisted of cooperation between the university and the Zen Maker Lab to support up to 60 engineering design students. The students were provided with tools, safety training, and support for manufacturing. The facility has provided CAD design stations, several 3D printers, laser cutters, and numerically controlled milling machines to support manufacturing of student designs.

Access to the manufacturing facility was initially provided on subscription basis, where students used the library to “sign-out” membership cards, and access the facility on a controlled, supervised basis. The controlling of student numbers through the university library provided a method for managing student access to the manufacturing facility over a period of 8-10 weeks. This arrangement for laboratory access has recently been expanded through a revised collaboration arrangement, and has provided engineering design students with hands-on experience with several manufacturing technologies and CAD engineering modelling and design tools.

Keywords: industry, collaboration, community-based, manufacturing, prototyping, engineering design.

1. INTRODUCTION

The Capilano University Engineering Transfer Program has continued to grow and evolve over the last several years. A one-semester Engineering Design course that provides hands-on design and prototyping experiences for first year students is a key element of the Engineering Transfer Program [1]. During the last several years the Engineering Design course has successfully provided students early exposure to several manufacturing technologies, and industrial manufacturing techniques.

Maintaining state of the art engineering design and rapid prototyping manufacturing facilities, however, especially under very limited university operating budgets, continues to be a major challenge for smaller teaching focused universities. As the engineering program enrollment grows at Capilano University, meeting the student’s hand-on experience during the design course required considerable exploration of innovative delivery models.

The purpose of this paper is to describe Capilano’s recent approach to complement the university’s laboratory facilities with access to a community-based rapid prototyping facility. Two variations of university-industry collaboration models were explored during the last two years, and the results of the collaboration are summarized in the paper. It is worth noting that an important aspect of the collaboration is to ensure adequate equipment operation training and introduce safety procedures for the students.

2. CAPILANO UNIVERSITY ENGINEERING

2.1. Engineering Student Enrollment

Since inception, the engineering programs at Capilano University have always operated at or near capacity. The enrollment was capped at 35 students for both the First
Year Transfer Program and the Transition Program until the 2015-16 academic year. From 2015-16 onwards, the cap for the Transition Program has been raised to 70 students. The effects on total enrolment are shown in Table 1.

Demand for engineering programs is trending upward in Canada and this is well reflected in the number of applications received in the program over the last few years at Capilano University (Table 1). The selection of stronger students from the enhanced applicant pool is shown in the improved first year GPA. Finally, the number of students enrolled in the design course studied is shown in the rightmost column.

Table 1: Capilano University Engineering class statistics

<table>
<thead>
<tr>
<th>Year</th>
<th>Applications</th>
<th>Incoming Students</th>
<th>GPA*</th>
<th>APSC 140 #</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-14</td>
<td>274</td>
<td>68</td>
<td>2.84</td>
<td>46</td>
</tr>
<tr>
<td>2014-15</td>
<td>367</td>
<td>61</td>
<td>3.16</td>
<td>42</td>
</tr>
<tr>
<td>2015-16</td>
<td>462</td>
<td>94</td>
<td>3.27</td>
<td>67</td>
</tr>
</tbody>
</table>

*Transfer Program only

2.2. Engineering Laboratory

The Capilano Physics Department provided a lab space of about 200 ft² for the duration of the term for 3D printing with a Makerbot Replicator Experimental 2X (Dual ABS spools) and a Makerbot 5th Generation (Single PLA spool) (See Figure 1). Both printers use a 1.75 mm filament with a 0.1 mm layer height. Tools such as files, pliers, screwdrivers, wrenches, cordless drill, dremel, a bench vise, soldering irons …) as well as solvents for cleaning the printer bed and for post-print processing (spatulas, utility knives, sandpaper) were made available.

Students had access for 32 hours of each week while the Physics lab was staffed. Faculty provided light 3D printing support and instruction. Sixteen work stations with Autodesk Inventor Suite were available for computer aided design.

2.3. Engineering Design Course

One of the main objectives of the Applied Science 140 Engineering Design (APSC 140) course is to allow the students to design, build and test prototype mechanical assemblies. For example in one engineering design class, these mechanical assemblies were required to support or attach electronic sensors onto an experimental drone [1]. These mechanical assemblies are designed by the student teams, typically 4 students per team, and are fabricated using various 3D printers and other tools. Although the engineering laboratory at Capilano University provides two 3D printers for the students, the peak load for testing various prototype designs during a one-semester design course exceeds the capacity of the university facility. To overcome the peak capacity limitation, a collaboration model has been set up with a nearby community-based prototype design and manufacturing facility.

3. UNIVERSITY-INDUSTRY COLLABORATIVE MANUFACTURING MODEL

Zen Maker Labs is a community-based creative and collaborative work space that brings together students, educators, designers, engineers, and artists to support design and prototyping activities in a variety of technology areas. One of the key elements of the maker space is the accessibility of computer aided design tools and workstations, as well as several prototyping manufacturing equipment, such as 3D printers, laser cutters, CNC milling machines, and various electrical hand tools.

By establishing a collaborative university-industry model, Capilano University explored the feasibility of using the facility to support the university in delivering a unique design experience for first year engineering students.

3.1 University-Industry Collaboration Requirements

The first step in the development of a collaborative working model was the definition and agreement to an initial set of requirements. The initial requirements for collaboration were:
a) Facility to be located in close proximity to the University with public transportation access (ideally less than 5 km distance)
b) Controlled student access to the maker space facility
c) Student access to design and prototyping facilities, including CAD workstations, 3D printing technology, laser cutters, CNC milling machines, electrical and manual hand tools
d) Defined student access hours, where equipment and supervision were available
e) Provision of training and safety instruction on the use of facility equipment
f) Technical design support
g) Relatively low cost to the University established on a per student basis

Once a set of requirements was established, two sequential pilot projects were introduced over a two-year period. For both pilot programs, the engineering department took advantage of the maker space capability to provide engineering students with direct exposure to a wide range of design and manufacturing equipment, normally not available to first year students.

3.2. Maker Space Facility Capability

The Zen Maker Lab provided design and prototype manufacturing capability and space for use by the engineering students. One of the Lab’s 3D printers is shown in Figure 2.

![Fig. 2. Zen Maker Lab 3D Printer.](image)

The maker lab facility provided various 3D printers as listed in Table 2.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>xyz printing da Vinci 3D Printer (Fused Filament Fabrication)</td>
<td>1.75 mm filament (ABS/PLA), 0.4mm nozzle, 0.1-0.3mm layer height capable</td>
</tr>
<tr>
<td>4</td>
<td>Geeetech Me Creator 3D Printer</td>
<td>1.75 mm filament .1 mm precision</td>
</tr>
<tr>
<td>1</td>
<td>Makerbot Replicator 2X (Fused Deposition Modeling)</td>
<td>1.75 mm filament (ABS/PLA) (0.0025-0.011mm precision)</td>
</tr>
<tr>
<td>1</td>
<td>Z Corporation powder 3D printer</td>
<td>Powder print (0.1mm precision)</td>
</tr>
<tr>
<td>1</td>
<td>Tinkerine Ditto Pro (Fused Filament Fabrication)</td>
<td>1.75 mm PLA filament (0.05-3 mm precision)</td>
</tr>
</tbody>
</table>

The Lab also provided access to two laser cutters, including 60 watt and 80 watt versions. The other equipment available was a Sherline mill with full CNC, and a custom build CNC router.

To round out the lab, other capability included several computers with 3D mechanical design software and CAD/CAM, assorted power tools (table saw, drill press, miter saw, grinders, jig saw, band saws), miscellaneous hand tools. Staff consultants were also available to assist the students in the following areas:

- 3D printing and design
- CAD CAM
- Electronics
- Networking
- Equipment training and safety

The workspace provided was sufficient, as folding tables were used when several students were working on smaller projects, or if more floor space was needed for larger work, tables were moved out of the way. In addition, a special conference room with a large screen display provided students with an environment that supported computer based drone flight simulations.

3.3 Initial Pilot Collaboration Model

The first collaborative agreement was initiated by the Capilano University library through discussion with Zen Maker Lab. A conceptual framework was developed, and final details were worked out between the library, the
Engineering Department, and Zen Maker Lab for the 2014-15 academic year.

The collaborative agreement consisted of a subscription-based model, where several subscriptions or “temporary memberships” were purchased by the library on behalf of the students. The subscriptions supported the engineering students over the 13-week period of the course. The students first accessed the library to sign-out the “memberships”, and used the “memberships” to gain access to the lab. The agreement specified times when students were allowed to access the lab. The agreed times were from normal operating hours during Monday to Friday, as well as specified evening access. The access agreement also included one two-hour evening tutorial for the engineering design class, where the capabilities of each major category of equipment was demonstrated, and safety procedures were discussed.

The costs for supporting this agreement were managed by the library on behalf of the Engineering department. Eleven teams from the Engineering Design course took advantage of the off-site facility, and used the CAD stations and 3D printers to fabricate some of their mechanical design assemblies.

3.4 Revised Pilot Collaboration Model

Based on student feedback from the first pilot project and with an increase in student numbers, modifications to the collaborative model were incorporated for the 2015-16 academic year. During this academic year, two engineering design sections were offered concurrently at Capilano University, resulting in a total engineering design course enrollment of 60 students.

To support the higher student numbers, a modified arrangement was concluded between the Engineering department and Zen Maker Labs, with the following additions to the initial agreement:

- Scheduled safety and equipment training were offered to smaller select groups consisting of two or three teams (see Figure 3).
- Each class was offered a detailed tutorial on 3D printing technology at the University.
- Student teams were offered pre-arranged dedicated time slots, where they were able to fabricate their designs, and obtain individual support during design fabrication.
- Workshop and conference room was provided during weekend hours to support drone computer based simulation practice and testing. (see Figure 4).

For this academic year, the costs for supporting this modified agreement were managed by the Engineering department. Sixteen teams from the Engineering Design courses took advantage of the off-site facility, and used the CAD stations and 3D printers to fabricate some of their mechanical design assemblies. A student pair finalizing their 3D printer design is shown in Figure 5.

4. RESULTS OF THE PILOT PROGRAMS

When comparing the results of the two pilot programs, both programs clearly supported the peak demand load of the prototype manufacturing requirements of the
engineering design class. Facilities at both the university and the maker lab were used extensively, especially during the last 4 weeks of each course. Both facilities increased their capacity to support student builds for the second pilot program, correctly anticipating increased student demand.

Although formal statistics were not gathered during the first pilot program, the design teams attempted at least two prototype 3D printer builds for their respective designs, stressing the production capacity at both locations.

For the second pilot program, the collaboration arrangement, now with increased production capacity at both locations, demonstrated that the two independent prototyping facilities adequately supported the students’ design and build needs by the end of the semester.

4.1 Lessons Learned from Initial Pilot Program

Several lessons from the initial pilot program were learned. A few of the key lessons are summarized below:

- With 11 teams participating, many students commented on the lack of flexibility to access either the University or the Maker Lab 3D printing, resulting in constant bottlenecks at both facilities.
- Additional training of the student on the basic use of 3D printers was required.
- Many initial designs were overly complex, resulting in students taking up considerable practice time on the 3D printers for their initial fabrication runs.
- 3D printers were notoriously slow, and subject to prototype fabrication failure, resulting in many additional hours of repeat print time.

Although there were challenges during the student prototype build attempts, all 11 student teams produced working 3D prototype assemblies that were incorporated into the final projects.

4.2 Improvements to Support the Revised Pilot Program

Based on feedback from the 2014-15 initial pilot program and lessons learned, the following improvements were incorporated as part of the revised collaboration model.

- Additional 3D printers were added at both the University and the Maker Lab.
- Additional access time and supervision was provided at both the University and the Maker Lab.
- Additional training, specifically on 3D printer technology was provided through a formal lecture at the university.
- Smaller group safety and equipment training at the Maker Lab was incorporated.
- Additional lab space for the 3D printers was provided at Capilano University laboratory

With an increase in engineering student participation in the 2015-16 academic year, more prototype assemblies were produced at both facilities than the previous year.

For the largest engineering design class (consisting of 10 design teams), over 30 prototype 3D print assemblies were attempted. Prototype 3D print job attempts ranged from one to five per team, with an average per team of three 3D prints fabricated. Each prototype print fabrication ranged from one to 5 hours of 3D print time. The Capilano University Engineering lab was the preferred choice by students and produced the majority of 3D prints.

The maker space lab also produced several 3D prints, but experienced bottlenecks during student peak usage periods. Although the facility bottleneck and new challenges arose, again, all student teams produced working assemblies that were incorporated into their design projects.

4.3 Recommendations for Further Improvements in Collaboration Models

Based on student feedback from the revised 2015-16 pilot program and previous lessons learned, the following improvements should be considered when developing such a collaborative program.

a) Investigation of an “on University Campus” Maker Lab” with staff seconded from industry, including experienced and practicing electrical and mechanical engineers should be considered. With an on-campus facility, the engineering students would have access to a design and manufacturing facility closer to their classes, minimizing travel time, and improving scheduling.

b) Further increase in the supply of 3D printers, improving student access and availability, as well as exposure to various manufacturing technologies.

c) On-line scheduling for student team access to 3D printers and other manufacturing equipment.

d) Instructors to encourage simpler engineering designs much earlier in the course to provide students with experience in using the manufacturing technologies prior to undertaking more complex designs.
5. CONCLUSIONS

A two-year experiment collaborating with industry in supporting an engineering design class at Capilano University has been described. The initial results of this community based collaborative approach shows potential for enhancing the engineering students learning experience. Although challenges were encountered with the university-industry collaboration models, the basic concepts provided engineering students with hands-on access and exposure to several new engineering design and manufacturing technologies in their first year of studies.

The largest challenge encountered during both years of the pilot programs was a consistent bottleneck of students wishing to carry out the fabrication of their specific designs at the same time, due to the extensive time taken to 3D print individual designs, and printer failures. A potential solution to the bottleneck is to encourage students to first practice on very simple mechanical designs, with less risk of printer failure, and extended print times. A formal online schedule for student access to individual manufacturing devices should also improve efficiency and reduce bottlenecks. Finally, an on-campus Maker Lab collaborative model should be investigated.

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References