

Interdisciplinary Prototype-Building Workshops

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Building and testing prototypes is an integral part of the design courses for both Biomedical (BME) and Mechanical Engineering (ME) at Johns Hopkins University (JHU). However, little training exists for students to learn basic prototyping methods. To fill this critical gap BME and ME collaboratively developed a workshop series to run in parallel with their design courses. Workshops were run as a laboratory to give students hands-on experience with the methods covered. Additionally, topics within the workshops were linked demonstrating the overlap from one method to the next. The topics covered were: 1) plastic bending and bonding 2) 3D printing and 3) molding and casting. Students from both BME and ME departments attended and learned relevant prototyping skills, subsequently using them in their design projects. Surveys used to initially measure the success of the workshop series revealed student desire for both more workshop topics and more in-depth workshops. Future assessment will include assessment of prototype progression and level of execution compared to prior years.

Keywords: interdisciplinary, prototype, workshops, hands-on

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Introduction

The design curricula in the Johns Hopkins University (JHU) Departments of Biomedical Engineering (BME) and Mechanical Engineering (ME) differ in several ways including project starting point, subject fields, sponsors, and team structure. This poses a challenge for creating multidisciplinary design education programs, an issue we know other universities struggle with. However, both disciplines require design teams to build and test their ideas and we identified that the skills required to do this was a critical gap in the education of students in both departments. We combined forces to this end, creating joint workshops that brought together faculty, staff and students in both departments towards a common goal.

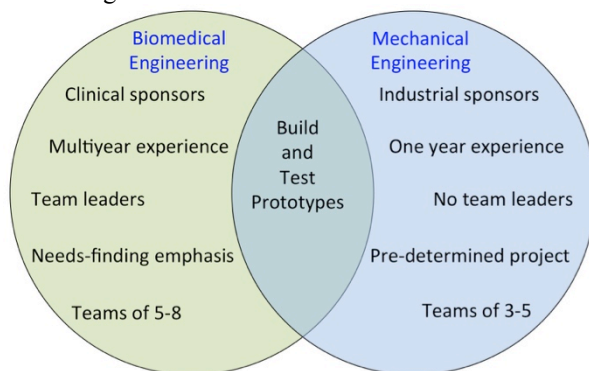


Figure 1. Curriculum differences between the JHU design programs in BME & ME

Prototyping workshops

In order to meet the needs of both BME and ME design students wanting to learn basic prototyping skills a series of three not-for-credit workshops was offered, each with two sessions due to popularity. The workshops were held in the evenings once per each month of the semester giving the students time to practice those skills before learning the next set. Holding the workshops in the evening had the distinct advantage that all problems of student scheduling and availability were avoided; a challenge when balancing the demands of the two different curricula.

While we had over twenty topics that we knew would be useful for students to learn, we picked three topics that we believed to be the most essential when starting to build prototypes. We also reasoned that the likely background knowledge of our students was low, and wanted to provide a set of concepts that would open up new capability quickly. We selected topics that demonstrated how technology could be complementary towards building advanced prototypes. They were also considered to be the most mutually beneficial to both disciplines.

The three topics were:

1. Plastic Bending and Bonding
2. 3D Printing
3. Molding and Casting

Early in the design process students need to be able to quickly build and test their ideas to determine

whether they're worth further developing. These three topics can help students do just that without the need for a large time or financial investment.

Once their design idea is determined to be worth pursuing, students can then use more advanced materials or incorporate electronics and other components into their systems.

In addition to these techniques being useful for quick building, we also wanted to teach students that multiple manufacturing processes can be used to build a product or prototype. The workshops culminated with teaching students how to create molds and casts. This could have been achieved using premade boxes and parts; however, to illustrate the concept of complementary technology the boxes built in Workshop #1 and the parts printed in Workshop #2 were used to create the molds and casts in Workshop #3, as illustrated by Figure 2.

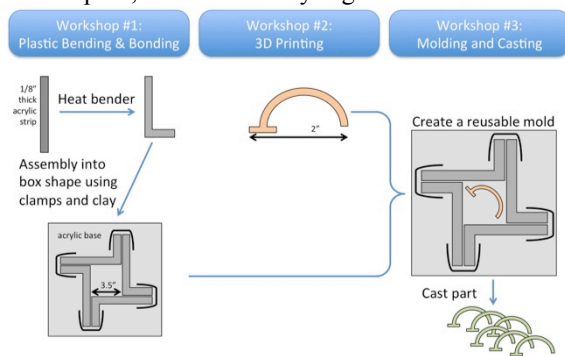


Figure 2. Technology sequence used in workshop series. Workshop #1: create a reusable box using acrylic and heat benders. Workshop #2: cantilevered bridge. Workshop #3: Use box from #1 and bridge from #2 to create mold and multiple casts.

How the workshops were run

Workshops were run twice in back-to-back sessions, with each session attended by a maximum of twenty students. A session was divided into five stations of four students, with students from both departments working at a station. This allowed students to work in small groups giving each one an opportunity to complete some of the tasks. The workshop also covered examples of past projects from both BME and ME, and different kinds of materials than the ones used.

In addition to the two instructors of the workshop, three to four graduate level BME and ME teaching assistants (TAs) were also present. The TAs were able to answer detailed questions and show the use of specialized equipment. Each department has its own equipment, but sometimes students need to use something that their home department doesn't have. To facilitate interactions between students and their non-home department, students were introduced to the faculty and staff responsible for teaching design in the two disciplines.

Workshop #1: Plastic Bending and Bonding

Learning outcome: build a watertight box using two methods: reusable joints made by bending, and permanent joints made by bonding.

Often, students need a watertight box of custom shape for testing purposes or as a component of their design, but do not know how to obtain such a box. Sometimes they turn to ordering premade ones which can be costly and not exactly meet their needs (e.g. through-holes are not in optimum location), or they resort to the variety of 3D printers on campus which is inefficient and also costly. In this workshop, we wanted to teach students how to build a box using two different types of joints: permanent and reusable.

Permanent Joints

Permanent joints are useful for designs housing electronics or for holding fixed components of the design. We introduced this concept by using 1/8th inch flat acrylic sheets pre-cut with castellations. Each station was given 4 edges and 1 base. Students assembled the box inside a fume hood and used acrylic glue to permanently create the joints.

Reusable Joints

Reusable joints were created using 1/8th inch flat acrylic sheets cut into 3" by 8" strips. Heat benders were used to create a bend in each strip to form an L shape. The box was assembled using clamps and clay and attached to a plain base (see Figure 2).

Workshop #2: 3D Printing

Learning outcomes: set up a build in a 3D printer and control the different parameters; and post-process the part once it has finished printing.

3D printing was selected as the second workshop topic as many of our students turn to this technology throughout their capstone design project. While many of them learn this technology on their own, they often make mistakes that can be costly and an inefficient use of time. We wanted to teach them about the different capabilities of the printers available on campus and provide demo pieces showing the strengths and weaknesses of each type.

Set up a build on a 3D printer

There are at least six different types of 3D printers available to students on the JHU campus, each with its own capabilities and limitations. As we could not cover all the different printers in detail, we chose to introduce the most common parameters.

These were:

- Layer height
- Printer resolution
- Object orientation
- Support material

Students were provided with four different *.stl files and guided through the set up of a build platform on the most commonly available printer on campus, MakerBot Replicator 2x™. Students were encouraged to change parameters and orientation and subsequently observe the effects of these changes on printing time.

Post Processing

Students often overlook the post-processing steps needed to convert 3D printed parts into a useable form. We choose four printers readily available on campus to the students to demonstrate different support materials and guided students through its removal.

A cantilevered bridge (see Figure 2) was built on the different printers and provided to each group of students. The printers used were:

- Objet 30 Prime™: blow-away support. Use high-pressure water to break away wax support.
- Dimension EST™: break-away support. Use fingers and tools to break the support away from the part.
- Fortus 400mc™: dissolvable support. Use a caustic bath to dissolve cellulose based support material.
- Uprint™: dissolvable support. Use a caustic bath to dissolve cellulose based support material.

Students were provided with various tools to remove as much of the support material as possible. For the parts printed on the Objet, students were then taught how to use a pressure washer for any remaining support material. There is no specialized equipment to remove left over support material from a part printed using a Dimension – which taught the students about the challenges of printing complex parts using that particular printer. The Fortus and UPrint parts with remaining support material were placed in a caustic bath, which is the equipment used on campus.

Further post-processing techniques such as sanding, painting, and using adhesives, were discussed using demonstration pieces.

Workshop #3: Molding and Casting

Learning Outcomes: create a flexible mold; and cast hard and soft objects from the mold

This workshop used the acrylic box with reusable joints built in Workshop #1 and the 3D printed cantilevered bridges from Workshop #2 (see Figure 2) to teach

students how to create a flexible mold and replicate a part through casting. This last workshop demonstrated to students how they can use several different prototyping techniques to achieve their desired part.

Creating a Flexible Mold

Learning how to create a flexible mold was considered important for the students in both design programs because it allows them to quickly create numerous parts at very little cost (compared to 3D printing).

To reduce the amount of time students watched polymers cure, half of the molds were created prior to the workshop by the TAs. The molds were made by: 1) putting a layer of clay in the bottom of the box, 2) pushing the 3D printed part into the clay about halfway deep 3) laying two cut up straws in the clay flush with the part and the box to act as sprue and riser, and 4) spraying the assembly with mold release. The mold material (Mold Star 16 fast) was poured over the clay and allowed to cure. This box with clay, 3D printed part, and cured mold material was given to the students at the start of the workshop. Students were then tasked with breaking apart the box by removing the clay, and creating the other half of the mold. Once the mold was cured they could proceed to casting a part.

Casting an Object

Once the flexible mold from the first step was cured, students then removed the mold from the acrylic box, as in the first step. With two halves of the flexible mold, they were then able to cast replications of the 3D printed part using Smooth Cast 300. While the part cured, students were encouraged to make shapes with the clay and cast these objects (e.g. a thumb, a ring, or a key). The students learned about the high fidelity of casting and the ability for these parts to replicate intricate details in the original parts.

The last part of the workshop taught students how to use a vacuum degasser, an essential part of many molding and casting projects. To do this, hard molds were made out of LEGO®, and Silgard 184 was poured into the cavity. The molds with the silicone were placed in the vacuum degasser to teach students how to use this kind of equipment.

Results

The workshops were considered a great success. The attendance for all three was at or close to capacity and equally attended by students in both BME and ME. Surveys given to the students indicate that they desire more experiences like this with more topics and more sessions. Specifically, anonymous survey results showed that 76% of students found the workshop series helpful towards the progress of their design projects. Direct quotes from comment sections of the survey

demonstrate the overwhelming positive response from this pilot:

STUDENT QUOTES:

The workshops were really great, well planned out and organized. They definitely contributed to my ability to further my project and know what is out there in terms of prototyping as well as which one I should choose.

Honestly, in addition to group time and individual mentorship, this should be what the rest of DT should be. All the needs statement, specification, concept generation lectures etc could have been readings we do on our own time. DT "lecture time" should be learning how to prototype, and working on our projects.

The polymer casting section I went to was great! I really like that we worked in small groups independently and got to experiment with the material.

The students appreciated the sequence of workshops and how they learned techniques that could be combined to strengthen their position in the design process. They learned that bending acrylic is not always a tool to make the final product, but it is useful in creating test fixtures and rigs for downstream building and casting. The 3D printing workshop demonstrated the capabilities of the many different printers available on campus. In addition to learning about printers and their capabilities, the students learned about how directionality in the material can create stress concentrations. Students learned that through creating molds of these parts and then casting them, weaknesses can be removed. A very powerful lesson!

Combining the two disciplines of BME and ME also proved to be advantageous. The students were able to ask each other about their respective projects and learn about the different challenges associated with each discipline.

Discussion

Creating multi or interdisciplinary design programs can be a challenge at universities, especially when said programs are well established and considered an integral part of their departments. While our goal to introduce multidisciplinary collaboration at JHU was challenging, we were able to overcome the differences between the programs (see Figure 1) by focusing on the mutual requirement of **building prototypes**. Efforts in this area at other institutions have included courses listed within a single department, while here workshops were run specifically mixing enrollment from mechanical and biomedical engineering design courses.^{1,2,3,4} We recognized that students in both disciplines lack key skills in these areas and we

identified topics that would be relevant to both. We also taught students that prototypes can be better built when a variety of techniques are used.

Through these workshops, undergraduate students were introduced to faculty, staff, graduate students and facilities in both departments, thereby reducing the barriers that students perceive to exist.

Future Work

Once results of the surveys are fully analyzed, we plan on incorporating the feedback into future development. While we wait for those results, we know that more topics such as microprocessors and motors, metal work, and advanced polymer work would be beneficial for our students and their capstone projects. We also plan on offering these workshops multiple times, thereby reaching more students. For all workshops, we were over-registered and could not teach all interested students.

We also plan to examine the quality of the prototypes presented in the respective design courses in the Spring semester. For those students who attended a workshop, we would like to assess, through surveys, the impact that it had on the students' design and build process. We also would like to compare the quality of prototypes made by students who attended a workshop to those from previous years. We hope to present these results at the Capstone Conference in 2018.

Lastly, as popularity for these workshops increases, we plan to offer an introductory prototyping building for-credit course that would be available to all students. This would allow students to be better prepared for their capstone experience, as well as learn important skills for the job market or graduate school.

Acknowledgements

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