AC 2010-470: DRAW BRIDGE DESIGN: AN INTERDISCIPLINARY, HANDS-ON PROJECT FOR FRESHMAN ENGINEERING STUDENTS

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Abstract

Engineering schools have long dealt with issues in recruitment and retention in engineering programs. Retention past the first year of study in engineering is often less than 50%. Efforts to address low retention often include a redesign of the first year of study, with the intent to of introducing engineering design early in the curriculum.

Toward this end, Ohio Northern University has developed a year long Freshman Engineering course sequence including the study of engineering design and analysis, technical communication and effective teaming. The course sequence culminates in a one quarter capstone design course. Various iterations of this course have included projects selected by student teams with few given constraints to a single project selected by the instructor with well-defined constraints. In these cases, the selection of the single project becomes most important. The course includes multiple disciplines of engineering, and failing to include one or more disciplines could dissuade students from remaining in engineering.

The design of a drawbridge, integrating Civil Engineering (bridge design), Mechanical Engineering (movement of the drawbridge mechanism) and Electrical and Computer Engineering (control and motor circuitry for the bridge mechanism) was assigned as the project in the capstone design class, and subsequently moved to an earlier prerequisite first-year course. This project involved the use of a specific engineering design process, significant hands-on activity as scale models of the drawbridges were built and demonstrated, and incorporation of truly interdisciplinary teams. Student evaluation results showed that the students found the activity stimulated their interest in engineering and encouraged students in independent thinking.

This paper will describe the project in detail, allowing those interested in replicating this project to do so. The details will include the bridge specifications and criteria, and results of testing. In order to assess the success of specifying the criteria, basic bridge designs will be presented. Finally, specific student evaluation data and descriptions of successes and future implementation plans from the instructor’s viewpoint will be presented.

Introduction

Recruiting engineering students has become a major challenge. Recent news about factories moving overseas and the outsourcing of jobs may easily give high school students the perception that our national industries are decaying, which makes the college of engineering a less attractive destination and a career in engineering very unlikely.

While recruiting engineering students is no easy task, retaining them is often no easier. Various engineering schools around the country struggle with a retention rate of less than 50% from freshman to sophomore year¹. A report issued by the National Academies² describes undergraduate programs in science and engineering having some of the lowest retention rates among academic disciplines.

Students drop out of engineering for multiple reasons. A significant group of students enter engineering with excellent high school academic credentials. Students may enter college with inflated expectations of their expected academic performance. Many students panic and question whether engineering is right for them if and when they receive their first “C”.

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Another group of students, the technology admirers, are quite determined to major in engineering as they have great expectations of all the “cool” things they will do in engineering. The problem these students find with some engineering programs is the lack of engineering in the first year; these students may be impatient and expect to start working with engineering projects as soon as they start their program. For many students in this group, the necessary freshman classes in math and sciences will be intolerable and the result may be transferring out of engineering.

In order to address these issues, many engineering schools around the nation are modifying their curricula to include at least one engineering class at the freshman level. Those classes may be designed to expose students to more interesting sides of their engineering programs.

The Freshman Engineering Sequence at Ohio Northern University

The Ohio Northern University first-year engineering program consists of a sequence of three engineering classes (one complete year in a quarter system). The sequence consists of GE104: Freshman Engineering 1 and GE105: Freshman Engineering 2, both involving instruction in engineering design and analysis as well as professional skills. GE106: Freshman Engineering 3 is the first-year capstone project course and the subject of this paper. The catalog descriptions of the three classes are listed below:

GE 104 - FRESHMAN ENGINEERING 1
The engineering profession and application of the engineering method: identification and definition of problems, consideration of assumptions and constraints, generation of problem solutions through the application of standard engineering techniques, and communication of results in standard formats.

GE 105 - FRESHMAN ENGINEERING 2

GE 106 - FRESHMAN ENGINEERING 3
A team-based conceptual design project based on the engineering design method: preparation of proposal, generation of design alternatives, consideration of constraints and criteria, selection of design alternative by decision matrix, testing and verification of design by prototyping, and preparation and presentation of design report.

GE106: Class Format and Objectives
The objectives of the class are as follows:
1. Teach students to work in teams to accomplish a goal.
2. Teach students how to generate and follow a project schedule.
3. Prepare students to develop and submit technical proposals and formal technical reports typical of engineering practice.
4. Teach students the correct process to validate designs using physical testing and other methods.
5. Train students to organize and present oral technical presentations.

These objectives are assessed by a set of individual and team assignments.
Individual Assignments
- Homework: usually based on material discussed in class.
- Presentation: Each group member must participate in either the presentation of the final report or the prototype demonstration. Individual grades are assigned.
- Peer Evaluations: The final grade of each individual includes a component which depends on evaluations by that student’s teammates.

Group Assignments
- Written Proposal: Each group is required to submit a written proposal in response to the Request for Proposals provided by the instructor.
- Intermediate Reports: Including written and verbal progress reports.
- Final Report: Each group will submit a formal written report at the end of the quarter.
- Each group must produce a physical prototype and demonstration of their proposed design.

Team Formation
In order to achieve the course outcomes, students in the class were asked to split into teams of 4 students each. It was mandated that every team must include students from at least 2 different disciplines (teams with 3 disciplines represented are preferable). Teams remained in tact through the whole quarter. The multi-disciplinary teams proved to be beneficial in different aspects. First of all, students were often forced out of their social comfort zone and grouped with students that are not necessarily their traditional friends or classmates. Moreover, by working in interdisciplinary teams, students had to split up the tasks in the project and team members were required to have effective intra-team communication. Teams were tasked to develop and submit a team charter to the instructor.

Project Assignment
From the instructor’s point of view, the biggest challenge of an interdisciplinary capstone course is identifying a project to be assigned. The project must be selected while keeping in mind that the assignees are only freshman-level students without any significant engineering background since at this point in their careers, they are not yet exposed to circuits, electronics, statics, or materials classes. In the same time, the class must be involved enough to keep students busy for most of the quarter and to satisfy their hunger for hands-on engineering projects.

Another challenge associated with the selection of the project is satisfying the different groups in the inter-disciplinary class. For example, at the end of the class in previous years, it was the norm to see students from one or more engineering disciplines complaining that the class project was mechanical or computer engineering oriented and that civil or electrical engineering majors didn’t get a lot out of this class. Considering the fact that each section of GE106 contains an arbitrary mixture of students majoring in four engineering disciplines (electrical, computer, civil, and mechanical), it was crucial to pick a project where all students can find their niche to work on.

Students were asked to design a draw bridge, like the one shown in Figure 1, with the following design specifications:
- Bridge should be 5” above the main surface
- Bridge should span an 18” wide river
- Bridge should be no less than 5” wide
- Bridge should be stable and hold 2 lbs weight in the center of the bridge
- Bridge should allow boats (up to 20” tall) to occasionally sail under the bridge down the river
- Use any type of material (wood, metal, plastic, etc…) or a combination may be used
- Use only raw material; pre-fabricated pieces (e.g.: Legos) are not acceptable
- Electric motors are suggested for any parts in motion. Any alternatives are encouraged.

In this project, civil engineering majors were mostly interested in designing the structure of the bridge and making sure it would stand even when it is holding 2 lbs of weight. Although they haven’t had any courses on structures or statics yet, they created their prototype, sometimes relying on trial and error until they obtained a satisfactory result. Even after a solid structure was achieved, students were still working on alternatives to achieve a lighter bridge as the weight of the bridge was part of the grading criteria.

Mechanical engineering oriented students were generally interested in designing the opening/drawing mechanism of the bridge. Similar to the civil engineering students, even without any prior exposure to design classes or design experience, mechanical engineering students designed gears and mechanisms that allowed safe and stable operation of the bridge.

Similarly, the electrical and computer engineering students enjoyed designing and installing the electric motor circuitry on the bridge. Without any prior exposure to circuits design, they managed to read the rating on the various motors and therefore picked the appropriate power supplies. They also learned how using a resistor will regulate the current flow and therefore regulate the speed of operation of the motor.

![Figure 1. Bridge specifications.](image)

The drawbridge project was the sole project during one iteration of GE 106, the First-year Capstone course. Two years later, the same project (with an accelerated time frame) was incorporated in the second course in the sequence, Freshman Engineering 2 (GE 105). The project was assigned over a 2 ½ week period in GE 105. The project in GE 105 required less documentation and review, and more information was given to the students to allow the compressed schedule.
**Grading Criteria**

The prototype in the capstone course was judged and a grade assigned based on the following criteria:

- Compliance with all constraints
- Weight of the prototype
- Speed of operation (opening & closing)
- Implementation cost
- Aesthetics and creativity

Students in GE 105 were tasked to develop the list of criteria by which the best bridges would be assessed. The list of criteria is as follows:

- Compliance with all constraints
- Weight of the prototype
- Speed of operation (opening & closing)
- Maximum weight supported
- Aesthetics
- Engineering creativity (a “wow” factor)

The “maximum weight supported” criteria was judged until the bridge failed or until a team asked for no more weight to be applied. The aesthetics and creativity scores were assigned by judges: in this case, aesthetics were judged by the administrative assistants in the College, and creativity was judged by other faculty members and the Dean.

**Realized Designs**

In order to come up with an appropriate design, the students researched existing drawbridge forms and shapes.

At the end of the project in GE 105, one group built a vertically rising drawbridge shown in Figure 2. In this model, part of the bridge is pulled up with the help of pulleys located at the top of the two towers of the bridge. Four groups built a single-sided drawbridge, shown in Figure 3. This is probably the most common type of drawbridge, where one side of the bridge acts as a pivot while the other side is pulled up using pulleys. One group designed a split (double sided) bridge, shown in Figure 4. In this design, the bridge is made of two different parts, each part has one side hinged while the other side can be pulled up to draw the bridge. Two groups presented sliding bridges, shown in Figure 5, where the bridge slides back completely clearing the river. Finally, one group modeled their “tilt bridge” design after the Gateway Millennium Bridge over the River Tyne in England. The entire roadway tilts up as counterweights lower, as shown in Figures 6 and 7. Finally, one group built a “swinging” or rotating bridge, where the structure spins out of the way of ships, as shown in Figure 8. This group used prefabricated plastic building pieces: this would have been a disqualification in the GE 106 project. However, given the compressed timeframe in GE 105, the design was allowed.

At the end of the quarter in GE 106, the six different groups ended up with functional prototypes which can be classified into 3 different models. One of the groups designed and built a vertically rising drawbridge, four of the design groups designed and built a single sided drawbridge, and one came up with a split (double-sided) drawbridge.
Figure 2. The vertically rising drawbridge (shown here during weight testing)

Figure 3. The single sided drawbridge (shown while testing with a “boat” made from styrofoam)
Figure 4. The split drawbridge (shown while testing with a toy automobile)

Figure 5. The sliding drawbridge (arrow indicates bridge movement)
Figure 6. The tilt drawbridge (shown partially open)

Figure 7. The tilt drawbridge (shown during weight testing: one team member is standing on the structure)
To evaluate the prototypes, a measurement station was set up where the bridges were weighed and their dimensions were measured. Each bridge was tested to ensure that it was stable enough to hold the specified weight. Once the testing was over, students presented their project with Powerpoint slides detailing their design process and the decision matrices; they finished the presentations by demonstrating the drawing mechanisms of their prototypes. All six groups in GE 106 and all ten groups in GE 105 ended up building functional bridges supporting the specified load and drawing/closing in a reasonable amount of time. One group in GE 106 did build their prototype with exactly an 18” length, not allowing any length to support the structure on the “sides” of the “river” and were assessed a point deduction, while one group in GE 105 implemented a hand crank since their motor didn’t function as designed and were assessed a deduction. Of the ten bridges described in GE 105, eight were able to support 47 pounds, the amount of weight available to test “total weight supported”, and two had team members stand on them.

Class Evaluation

During the last week of their class, students in one section of GE 106 were asked to fill out a survey assessing their learning experience. Students in the GE 105 class were given the same survey using a Web-based survey instrument offering anonymity during final exam week (after their demonstrations), therefore lower response was expected. Twenty-two of 24 students enrolled in the section of GE 106 participated in the survey, while 33 of the 120 students in GE 105 participated. In each question, students were given a statement and were asked to indicate their degree of agreement. The possible options given included strongly agree, agree, neutral, disagree, or strongly disagree for each statement. Table 1 shows a list of the statements and the distributions of the responses received from the survey.
Table 1. Results of end-of-quarter survey assessing student learning experience

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>My interest was stimulated in the subject matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE 105</td>
<td>10</td>
<td>12</td>
<td>8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>GE 106</td>
<td>10</td>
<td>11</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>I was encouraged to carry out creative/independent thinking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE 105</td>
<td>9</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>15</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>The course enhanced my problem solving abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE 105</td>
<td>5</td>
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<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>GE 106</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>The used teaching methods helped me learn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GE 105</td>
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<tr>
<td>GE 106</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

While the sample size was small, student responses supported the impression of the instructor: the students found the project stimulated their interest in engineering. Students also indicated that they overwhelmingly found that the course encouraged creative thinking and enhanced their problem solving abilities, both of which are goals of the course. The observation of the instructor was very similar to the results shown.

Student comments supplied from the GE 105 population were very positive. Negative comments were given based on the compressed time schedule, and the unfortunate coincidence of the shop being closed over the weekend when most construction would have occurred.

Positive comments included:

“Great project!!”, “I liked it” and “It was a fun and challenging assignment”. More descriptive comments included:

- The project was a positive learning experience. I learned how important design constraints and criteria are in the design process and how the affect the finished product. More time should have been allowed to work on the project to allow groups to explore more design possibilities and construct test bridges. I think that at least 3 weeks would be a good time frame for a project such as this.
You could assign it at or near the beginning of the quarter and have it due at the end. This would allow for more time to go into the whole process and would help groups that had members with busy schedules. Overall it was a really good project though.

While almost all comments were positive or cited the lack of time, one did cite a lack of mathematical basis for the compressed GE 105 project:

- I would have liked to be able to use equations and have more of a design process in the experiment. I felt like it was hard to do this experiment without just throwing something together with little planning. I also felt that there was not enough time given at all to do this experiment (only 2 weeks).

This point is discussed in “Future Plans”.

Future Plans

This project was very successful as an interdisciplinary project within the Freshman Capstone course. Future plans for the drawbridge project include continuing to incorporate it into the second course in the sequence, GE 105 (Freshman Engineering 2) rather than in the capstone course. This allows the restructure of the capstone course to allow students to select their own projects.

Incorporating the drawbridge project into the second course of the sequence allows the instructors to assist as the project is developed and the prototype designed and built. In the future, the time allotted to the project will increase: students will be given information on the design process including a schedule they will need to follow to finish on time, guidance on materials which can be more effective in construction, and in-class time will be allotted for discussion on the different types of bridge design. Future project plans call for a three to four week period, which will include problem definition, with discussion of the information needed to design the bridge, criteria for judging the bridge performance and constraints that each group will need to consider. Basics of truss design and equations for determining the load of the bridge will be covered. Problem definition is followed by the design phase, including analysis of design alternatives. This portion will have in-class discussion time allotted; it seems that discussion of design alternatives (and perhaps the inclusion of “engineering creativity”) led to greater variability among the designs. Verification follows the design process: in-class discussion on testing methods will most likely ensure that all groups follow a successful test plan. Groups will continue to be required to prepare a formal written report and formally demonstrate their prototype to the class.

The intent is that incorporating the project into the quarter prior to the first-year capstone course will help student teams progress successfully through the engineering design process and successfully demonstrate projects at the end of the capstone course.

Conclusions

The drawbridge project was very successful as a project in the first-year capstone course and the course prior: all of the bridges designed and prototypes built by student teams were successful (with one exception in required bridge length and one with a failed motor design). Survey results showed that students found the project to stimulate their interest in engineering and that the project encouraged creative thinking. Informal assessment from the course instructor found similar results: during team meetings, students were generally excited and engaged in the process.
The teams were interdisciplinary, and students from each major were able to be actively involved in a portion of their project that related to their major – sometimes very difficult to do for interdisciplinary projects, especially during the first year of engineering study.

The project will be implemented in the course just prior to the capstone course, and serves as a vehicle to learn and demonstrate the benefits of effective engineering design. Institutions wishing to use this project may do so simply by varying the amount of instructor assistance and amount of information given to student teams throughout the process.

In all, the drawbridge project represents a successful, interdisciplinary project suitable for the first year of study, and is shown to be interesting and engaging to students.

References

