AC 2012-4613: IMPROMPTU DESIGN EXERCISES IN AN INTRODUCTORY MECHANICAL ENGINEERING COURSE

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Impromptu Design Exercises in an Introductory Mechanical Engineering Course

1 Introduction

In this paper, the use of impromptu design exercises in an introductory mechanical engineering course is presented. These exercises are used to introduce three design concepts: 1) the design process (in general), 2) brainstorming and decision making, and 3) optimization. The developed exercises are presented along with details pertaining to implementation and preliminary evaluation results.

The impromptu design exercise format [1-3] is commonly used at engineering student functions, like conferences, as a fun, ice-breaker activity [1]. In a typical contest, students are given a simple design task capable of being completed in a short amount of time, a bag of (carefully chosen) supplies, and nothing else. The student team approaches the problem as they best see fit – this may include trial and error, design-build-test-redesign, and any number of different design approaches. When complete, the designs are tested to determine a "winner" based on some predetermined metric.

Aside from using impromptu design contests in university courses as ice-breakers [1, 2, 4], little research has been carried out on using impromptu design to achieve desired educational outcomes. The current research in this area has focused on the ability of impromptu design contests to foster creative thinking and team building [1] – it is noted that they have been proven quite effective in this regard. Preliminary findings regarding the use of impromptu design as a vehicle for engineering design education show promise [3, 5, 6].

Impromptu design exercises provide a unique opportunity to teach design concepts. Specifically, because student groups are "thrown" into the project they learn by doing. This type of active pedagogy has been shown to improve student understanding. Furthermore, by referring to the project in later discussions, it provides a "jumping-off" point for lecture/discussion on more advanced engineering concepts – which is how the projects are used in this paper.

In this paper, the developed exercises are presented with some discussion regarding their implementation. Some of the main findings in this paper are:

- Students really enjoy these exercises – this student engagement should be expected due to the hands-on, competitive nature of the exercises.
- Preliminary exercise assessment shows that desired learning objectives can be achieved using this pedagogy.
- Students see them as an important part of their design education experience.
- Although they have some advantages, there are a number of difficulties associated with developing and implementing these projects.

The remainder of the paper is organized as follows. Impromptu design exercises are discussed in detail in section 2. Section 3 presents the developed impromptu design projects along with implementation issues. Section 4 presents some preliminary evaluation results and, in section 5, conclusions are offered.

2 Impromptu Design Exercises

In a typical impromptu design exercise, students are given a simple design task capable of being completed in a short amount of time, for example 15 minutes or one class period. The problem is introduced as follows:

> **Need:** This give the exercise context and simply states the need that is being addressed.
>
> **Problem:** This states how the need is to be addressed.
>
> **Scoring Metric:** This gives a way of judging designs – could also have constraints.

Students are also given some materials (usually office supplies are used as they are readily available). In addition, shared tools, such as scissors, are also made available. The student team then approaches the problem as they best see fit with minimal guidance from the instructor – the only instructor guidance is rule clarifications.

After the allotted time, students are asked to reflect in groups on their experience. The class then comes together to share the reflections and a lecture is given regarding the underlying concepts covered by the impromptu design exercise. Note that the reflection, discussion and lecture are critical because they solidify the concepts that are somewhat self-taught during the impromptu design exercise.

2.1.1 Motivation for the use of Impromptu Design Exercises: The educational research on design education is specifically focused on design as a behavior – that is to say that the act of design is a set of actions that the engineer does [5]. Thus, in order to develop this behavior, engineering students require a significant amount of design practice, along with proper reinforcement – one suggestion is that several simple design problems precede the larger capstone design project [7]. In addition, design and other engineering subjects are best learnt through hands on active learning, e.g. project based learning [6, 8]. Therefore, the integration of impromptu design exercises into all aspects of the curriculum is motivated by the above research findings.

In addition, the authors have found that these projects have a number of other advantages including:

- Using these hands-on activities give students concrete examples of the issues being discussed in class – e.g. students go through an impromptu design exercise (where they design and build, for example, a bridge) and then models of the design process are discussed.

- Students really enjoy these projects and are left wanting more – this is clear from student responses on end-of-the-semester class evaluations, where students often say they wished they have more impromptu design projects.

- These exercises offer instructors a way to assess student understanding (both by the instructor and the student themselves).

2.2 Difficulties with this approach

Despite the advantages of impromptu design exercises, there are a number of difficulties associated with them.

- Instructors have to determine which topics in their courses offer the most promise for being taught or reinforced through this type of pedagogy. In general, the authors propose that the most important topics in a given course are reinforced by these exercises.

- While writing the impromptu design exercise (need, problem, metric) might appear to be a trivial task, the specificity and clarity of the need and problem statements greatly affect students' ability to uncover the instructor's expectations of them.

- Determining the amount of time to allot for the exercise is difficult. As mentioned, follow-up reflection and discussion are of key importance. Furthermore, it is best to have these reflections on the same class day as the exercise. Thus, exercise time is critical.

2.3 Comparisons with other design pedagogies

One of the motivating aspects for the presented impromptu design pedagogy is the success of active learning [9] – for example problem based learning (PBL). However, these pedagogies do not seem to be the norm in engineering education – for example a 2006 study found 44.7% of design education research papers (taken from 12 sources) from 1994-2001 discussed typical semester long design projects and only 11.4% discussed problem based learning [10]. The authors see this gap between the research and implementation as stemming from a need for greater project simplicity and lower project impact on class time (after all, there is little extra time in engineering science courses.) This need can be met by the relatively simple and short impromptu design exercise pedagogy. In order to put the presented work in context, impromptu design exercises are compared to long-term projects below.

Impromptu design exercises differ from long-term projects in a number of ways. First, impromptu design exercises are short tasks capable of being completed in one class period. Second, this necessitates that the problem formulation (e.g. need, constraints, and evaluation metrics) and materials to be used are given by the instructor – this is perhaps an advantage of longer projects where students take part in all aspects of the design process. Finally, the pedagogical goals of impromptu design and long-term projects are quite different – impromptu design exercises focus on the application of one or two particular concepts, while long-term projects are typically focused on a larger amount of material. These differences enable impromptu design projects to be simpler and shorter.

3 Impromptu Design Exercises

The impromptu design exercises used in an introductory mechanical engineering course, ME2505 Mechanical Engineering Analysis and Design, at Villanova University are presented. Two sections of the course were offered with a total of 64 students. The course was detailed in [11]. In summary, the key goal of this course is to give students a hands-on introduction to mechanical engineering, including the engineering design process, making the course a perfect fit for the impromptu design pedagogy.

In order to introduce design concepts, three impromptu design exercises were developed and implemented. These exercises focused on three important concepts: 1) The engineering design process, 2) Decision making, and 3) Optimization. Each of these projects is presented and discussed below.

3.1 The engineering design process

The following impromptu design exercise was carried out during the first week of classes – so it doubled as an ice-breaker. The desired outcomes from this project were:

- To introduce the engineering design process
- To introduce team members to each other (teams in this class are kept through the entire semester.)
- To get students thinking about some of the difficulties associated with the design process.

Problem Statement: It is important to get students interested in the problem. For this purpose, it is useful to tell a story, show a video, or relate the coming project to some pop-culture reference (like a viral video). To introduce this project, a viral video, Charlie the Unicorn[1], was used – see portions of the slide used in Figure 1. Note that the video was not shown in class, but rather referred to, assuming students had seen it.

Then the problem statement was given as:

> **Need:** Charlie the Unicorn needs to build a bridge to escape Candy Mountain
>
> **Problem:** Design a bridge from straws and marshmallows in 25 minutes
>
> **Constraints:** Charlie weighs the same as 50 pennies.
>
> **The winning design is the longest bridge that can hold 50 pennies.**

[1] www.filmcow.com

Figure 1: Slide used to motivate the impromptu design process, showing images from the viral video Charlie the Unicorn (pictures taken from www.filmcow.com).

Materials: The supplies given to the students were a plastic Ziploc bag containing 20 straws, 10 marshmallows, a roll of pennies and a Styrofoam cup. In addition to these supplies, scissors and additional pennies were available at the front of the room.

Project Time: The amount of time given to the students was 25 minutes. This allowed for the necessary introduction (5 minutes) and reflection and discussion (20 minutes). Note that a lecture on the design process was also planned to be given during the next class session.

Student Designs: Some examples of student designs resulting from the project are shown in Figure 2. It is always interesting to see the diversity of bridge designs.

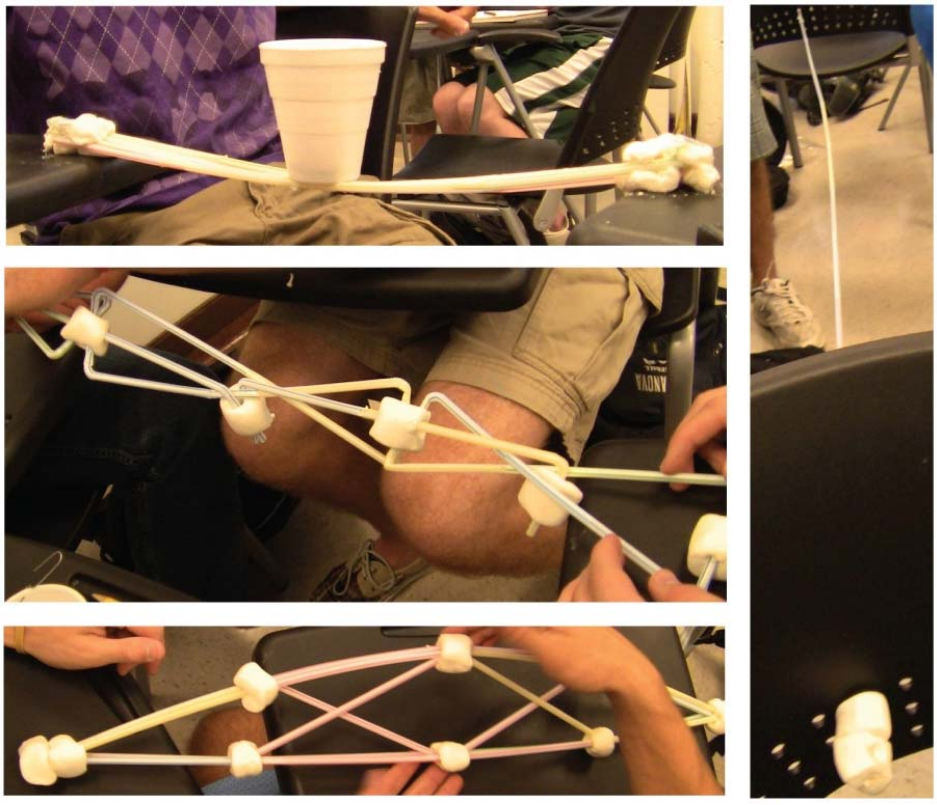

Figure 2: Example impromptu designs: marshmallow and straw bridges.

In-class Reflection/Discussion/Lecture: Following the exercise, students are asked:

> "What steps did you follow as you built your … (truss structure for example)?"

Students are given time to reflect on this question both individually and in groups. Each group is then asked to make a list of steps it followed when solving the design problem. In doing this, they are developing a model of the engineering design process they followed. Finally, the student teams are asked to share their individual design models with the class.

When the discussion about the different design approaches is complete, a lecture about different models of the design process was used to help solidify the impromptu design's introduction to the design process (this lecture was given on the following day).

Instructor Observations and Preliminary Evaluations: For the past five years the authors have used this impromptu design exercise to introduce the engineering design process to freshman and sophomore level mechanical engineering students. In this time, it has become clear that the students truly enjoy the activity.

In the fall of 2011, 64 students were given a survey directly following this exercise. When asked:

> "What did I learn through this in-class activity? (knowledge, skills, attitudes),"

students responded:

> "How to work as team; how to improve design"
>
> "Patience"
>
> "The initial plan is very important"
>
> "Some ideas don't always work, but there's no harm in suggesting"
>
> "I learned how to build a bridge with straws and marshmallows"
>
> "Think outside the box…"
>
> "It is important to work fast, but plan ahead"
>
> "Don't build a bridge out of marshmallows"
>
> "The task was not as easy as it looked"
>
> "I learned that it's not always a good idea to spend most of the time brainstorming and to set aside more time for testing and redesign"
>
> "Time management is important"

Overall, these responses show that the exercise objectives were met – students were introduced to the design process, were introduced to some of the difficulties with design (e.g. time management) and the student teams were introduced to each other. For more information on this project see Ref [3].

3.2 Decision Making

The learning objectives for the following exercise were to introduce engineering decision making and to revisit brainstorming. In order to pique student interest, the class's semester long design project, focused on building a "Beetlebot", was used – in this project a remote controlled robot which weighs less than 3 pounds is designed and built to fight against other "Beetlebots" in an enclosed eight foot by eight foot arena.

Problem Statement: The problem statement was:

> **Need:** Your beetle-bot needs to defend itself.
>
> **Problem:** Brainstorm ideas for Beetlebot weapons.
>
> **Scoring Metric:** The team with the most "valid" ideas wins.

Once brainstorming was complete, students were asked:

> Choose your best design.
>
> Please keep track of how/why you made your decision.
>
> Each group will present their results.

Note that this is a slight variation on the typical impromptu design exercise format because nothing is built. It still falls under the impromptu design umbrella because of its short, impromptu nature.

Materials and Time: For this exercise, no materials are needed and, since no building is required, a very short amount of time is required (10 minutes).

In-class Reflection/Discussion/Lecture: Directly following this exercise, the best ideas from each group were collected and written on the board. Then a discussion of why the students chose that particular design was had. This discussion led to the idea of using design criteria to make a decision. With the best ideas identified and the idea of design criteria established the following questions and comments were discussed:

- What if the "best" decision isn't clear?
- What do you do if there isn't time/money to make a more informed decision?

- What aspects of a design are important?
- How do you rate each design with respect to these aspects?
- Are some design aspects more important?

This then led directly into a discussion of design criteria, metrics, and design matrices for choosing a design. Note that in each of these steps, the original problem was carried through in order to find a "best" solution.

Instructor Observations and Preliminary Assessment: This project although well received, was not as popular as the other two exercises presented. The author feels that this is due to the fact that there is not a hands-on component. In the future, this project will be augmented with some hands on activity. It does appear, however, that the goal of introducing decision making was achieved because students received an average score of 9.4/10 on the decision making problem on the final exam.

3.3 Optimization

The goal of this impromptu design exercise is to introduce the concept of optimization to the students.

Problem Statement: The problem statement is as follows:

> **Need:** Your brewing company needs a new storage tank.
>
> **Problem Statement:** Design and build a model of an enclosed beer storage tank.
>
> **Scoring Metric:** The team with the greatest volume wins.

Materials: The materials given to the students were one folder, tape, and scissors.

Project Time: The project time was chosen as 20 minutes, which left time for problem introduction (5 minutes), reflection (5 minutes), and a lecture (20 minutes).

Student Designs: Some examples of student designs resulting from this project are shown in Figure 3.

In-class Reflection/Discussion/Lecture: When complete the designs were compared and discussed. This was followed by a lecture on how to choose design parameters optimally. The problem was restated to build the *largest volume cylindrical tank* in order to limit the design space. Then two techniques for mathematical optimization were presented: 1) Differentiation and 2) Lagrange Multipliers.

Figure 3: Example impromptu designs: beer storage tanks.

Instructor Observations: Overall, this project was very well received. Some of the instructor observations were:

- Some students were quite creative with the rules – for example students used tape as a structural component, which meant they could design much larger volumes.
- Many students had interesting discussions about optimal tank shape and using mathematical equations to determine optimal ratios (without prompting).
- Some students finished early, so I asked them to choose a name for their beer company and design a logo.
- Again, a wide variety of designs resulted from the project as can be seen in Figure 3.
- As this was the third project given in the semester. Things ran very smoothly and the students needed almost no prompting to stay on task.

4 Preliminary Impromptu Design Evaluation

One thing is clear from the evaluation carried out on these impromptu design exercises: students see them as a contributor to their design education. At the end of the semester, a general course evaluation was given. This survey included the open ended question:

> Do you think that you learned engineering design in this course? If yes, HOW (through what classroom readings, activities, discussions, etc.?)

Without prompting 35% of students mentioned the impromptu design projects. This may not seem like a huge percentage, but in a class where there are numerous ways to learn the design process (hands-on laboratories, homework, Beetlebot competition discussed above, impromptu design, other in class projects, etc.), a 35% share of responses is actually quite significant. This shows that students were indeed interested in the projects, but also that they perceive them as being a good education tool.

5 Conclusions

In this paper, the use of impromptu design exercises in an introductory mechanical engineering course was presented. These exercises were used to introduce three design ideas: 1) the design process, 2) brainstorming and decision making, and 3) optimization. The developed exercises were presented along with details pertaining to implementation and preliminary evaluation results. Evaluation results showed that the impromptu design exercises had an impact (at least in the student's perception) on their engineering design education.

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