ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #16729

Rapidly Deployable Prototyping Activities to Teach Engineering Design

Dr. Matthew Wettergreen, Rice University

Matthew Wettergreen is a lecturer at the Oshman Engineering Design Kitchen. He teaches engineering design courses, including first-year engineering design and their follow on engineering design courses. Additionally he provides education via hands-on workshops and formal courses that teach students how to manufacture prototypes via low fidelity prototyping, iterative design, and the use of advanced manufacturing tools to produce high quality functioning devices. Matthew received his Ph.D. from Rice University in Bioengineering.

Mr. Timothy J. Hinds, Michigan State University

TIMOTHY J. HINDS is the Academic Director of the Michigan State University College of Engineering CoRe (Cornerstone Engineering and Residential) Experience program and a Senior Academic Specialist in the Department of Engineering Undergraduate Studies. His current teaching and management responsibilities include development, delivery and administration of first-year courses in engineering design and modeling. He has also taught courses in machine design, manufacturing processes, mechanics, computational tools and international product design as well as graduate-level courses in engineering innovation and technology management. He has conducted research in the areas of environmentally-responsible manufacturing, globally-distributed engineering teaming and early engineering education development and has over 30 years of combined academic and industrial management experience. He received his BSME and MSME degrees from Michigan Technological University.

Rapidly Deployable Prototyping Activities to Teach Engineering Design

Abstract
This paper describes kits that were deployed in a freshman engineering design course and used to enhance understanding of the engineering design process. In a first-year engineering design course student teams were given instructions and a kit of physical materials to work with. The instructions present a design challenge that can be solved through the creative assembly of the materials, as well as outline rules, timing and scoring of the challenge. Each activity can be completed in as little as one hour. Brevity of the assignment forces student teams to think quickly and rapidly functionalize ideas. Student teams use the time to complete the challenge and then compete against each other with their finished product. An example of one of these challenges is tasking the teams to develop a launcher capable of transporting a ping pong ball the furthest using a collection of low fidelity materials. Scoring is based on a strength to weight ratio.

The activities are designed such that student teams are most successful when they allocate time in the challenge and methodically proceed through the design process. The steps that each of these kits focus on are planning, defining the design criteria or success criteria, brainstorming, prototyping, testing, and iterating. Before and after the activity students take a survey that assesses their understanding of the engineering design process and queries how they would allocate time in a similar challenge based on the steps of the design process.
We detail the student and faculty experiences and provide preliminary data from our pilot deployment of these kits. We will provide sample kits for other faculty to take home and solicit suggestions for adoption in other programs.

Introduction
Engineering design is a core component of any engineering education. Most students take some form of engineering design in their capstone experience, as is recommended by ABET [1]. Recently, however, more opportunities for this work have been created for underclassmen. Studies have shown that placing team-based engineering design earlier in an engineering curriculum can provide students with valuable teamwork skills and connections to real-world engineering work, as well as increase retention of material learned in class [2]. Teaching design freshman year increases retention of women and underrepresented minorities[3]. It also provides relevance and context to young engineers' careers.

While there is an increased interest in teaching engineering design, understanding how to teach it is still a challenge. Teaching engineering design requires instruction of process not content, something that is often foreign to students and instructors. When teaching engineering design in the classroom the format should focus more heavily on active learning than the traditional passive learning formats. Learning engineering design and practicing engineering design are two different things.

The traditional engineering classroom typically includes greater fractions of passive learning than active participation. Concept understanding and knowledge retention have been shown to be higher with a variety of active learning types, such as problem based or active learning. [4].

In typical classes students are assessed based on performance on problem sets and tests that require knowledge gains from textbooks and lectures. Assessing engineering design is different, however, as it is based on evaluating students' execution of processes explained in class, rather than quantifiable test outcomes with correct answers [5]. Repeatable methods to test process-execution are needed.

The engineering design process is a decision-based process that can be used to break down and solve large and complex problems. Each university teaches a variation of the basic steps of the engineering design process: clarifying the problem, understanding the problem and context, defining design criteria, brainstorming, prototyping, testing, and documentation. A central feature of the engineering design process is iteration. Iteration is used to cycle backwards to repeat steps when new information has come to light, when failure occurs, or when an alternate option needs to be explored. Success in the engineering design process requires a mindset that encourages iteration and revision as a once-only run through of the engineering design process is surely to yield mundane or already-attempted solutions.

Teaching iteration in a lecture course is nearly impossible. The process of iteration includes making assumptions, creating artefacts based on those assumptions, testing those assumptions, synthesizing results and ultimately starting over with refined assumptions. Through these steps new information about a problem is generated, which influences the next steps [6]. Simply lecturing about these steps is insufficient to give students the experience necessary to effectively iterate in teams. Failure is one of the main reasons for iteration, but is difficult to teach about. The ability to identify and assess failures or other reasons for iteration can only be properly learned through hands-on experience. Previous studies have highlighted the ability to teach such concepts using hands-on activities such as model building and laboratory exercises. Lemons et al. showed that model building helped students generate ideas, make ties between concept and physical object, and finally make the students more away of their process-based strategies [6]. Mackenchnie and Buchanan have employed hands-on activities in a laboratory class using a building component [7].

The current work aims to teach crucial aspects of engineering design in short periods of time by providing students with simple building-based kits. Students use these kits in the classroom to solve challenges requiring steps from the engineering design process. The activities can be completed by most students as they require only practical ingenuity and creativity. Teams need to rapidly move through the steps of the engineering design process and iterate based on what they learn in order to be successful. These kits also provide instructors with an application of the design process to base student performance evaluations on, rather than typical question and answer.

Kit Development

The kits originally started as active learning challenges developed by faculty and staff at the Oshman Engineering Design Kitchen at Rice University. These kits were originally used for challenges offered at weekly lunch time events called INNOVATE Challenges [8]. These events were open to the public, students, and faculty. Attendees would draw a random number that would place them on a team with three other people. Participation was limited to 45 participants

(15 teams), on a first come first serve basis. The challenge would be announced promptly at 12:05, begin immediately, and run for less than an hour. Prizes were awarded for the top teams.

Challenges were adopted from a number of sources, including St. Louis University's Weekly Innovation Challenges [9], Teampedia.net, a wiki-based website that lists team building exercises, and from brainstorming sessions with Rice instructors. Challenges were scoped to be completed in the one hour period including set up and breakdown. Before running a challenge during an INNOVATE event, the challenges were workshopped and played through numerous times by staff and professors to adjust to the right level of complexity based on time constraints and student experience. Complexity was added to each challenge by adding design specifications, or setting minimum criterion which were difficult to achieve. The goal was to set a difficulty level such that it was easy for teams to complete the process-based steps of the challenge, but alone would not guarantee success in meeting the design criterion. Instead, students or teams would have to make a leap, either creatively or intellectually, to innovate upon the challenge solution in order to meet the success criterion. The leap could only happen if students completed a build and test iteration cycle. Complexity of the challenges were adjusted to suggest iteration as a necessary step to meet the success criterion, rather than merely going through the steps of the design process.

These challenges were later adapted and new ones developed to be deployed in a number of circumstances. The first ancillary product of these challenges was to teach workshop participants how to use low fidelity prototyping to communicate ideas and solve problems [10]. Low fidelity prototyping is a process that champions using readily available materials to build rapidly with low attention to aesthetic appeal and a strong focus on developing practical solutions. These workshops were taught with a kit of materials collected to run any of the challenges. Teams could then use the low fidelity materials and skills from these workshops for future projects.

The second evolution of these challenges was to teach students the engineering design process, specifically the iterative aspects of building and testing. Success in the challenge is dependent upon how quickly teams can iterate, not quality of craftsmanship, aesthetics, or other surface level characteristics. One of the challenges was introduced at Michigan State University for EGR 100 - Introduction to Engineering Design. This is a two-credit course taught in a lecture and laboratory format. Course learning objectives focus on engineering design and project management, technical communications, teamwork and engineering professionalism. Flipped classroom lectures are held once each week for 50 minutes throughout a 15-week semester. The laboratory sessions meet once per week for 110 minutes each. Lectures are held in a traditional auditorium, whereas the laboratory sessions are held in a computer lab facility with Windows®-based PCs. Lectures primarily deal with the various aspects of design, communication and the engineering profession while introducing students to the NAE Grand Challenges. Laboratory sessions concentrate on applications of the lecture topics through individual and team-based assignments and small projects related to two team-based major design projects. One of the challenges used in these lab sessions, the ping pong ball launcher, was one of the small projects, termed "Team Design Exercises," administered Fall 2015.

Sample Kit Description and Contents: Ping Pong Ball Launcher

Each kit contains three components: an instructor procedure, a student set of instructions, and collected materials. The materials can be assembled for each kit or as part of a larger collection of prototyping materials available to teams. Appendix A includes the challenge instructions for the student teams. When students arrive at the lab they are given instructions for the challenge, and informed of the time constraint. The instructors have already been given the guide on how to execute the challenge. The timing of the ping pong ball exercise allows for iteration and revision, a necessary component of the challenge. When this challenge was originally workshopped with undergraduate engineering students most teams developed completely unique ping pong ball

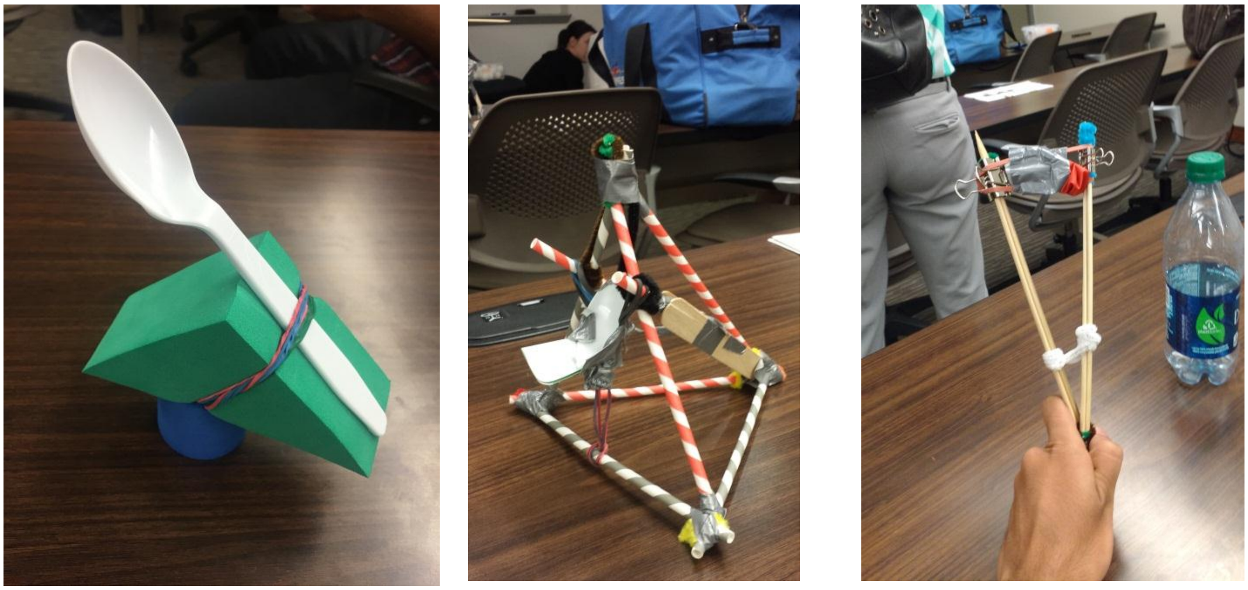

Figure 1. Three ping pong ball launchers built by students in a build workshop.

launchers, as shown in Figure 1.

The following components are provided for each team: 10 popsicle sticks, 20 assorted rubber bands, 2 each large, medium, and small binder clips, 2 clothes pins, and 1 ping pong ball.

Other challenges have been developed that similarly use readily available materials and can be completed in an hour. These challenges are identified in Table 1 along with the intended engineering design skills that we aim to teach.

Table 1. Table of prototyping challenges.

Challenge Specifics	**Engineering Design Skills (see legend)**	**Special materials needed**
Ping Pong Launcher: Launch a ping pong ball the furthest distance. Scoring is based upon distance divided by weight.	B, D/B, T, I, C	Office supplies, ping pong balls
Pick Up Sticks: use a limited palette of tools to transfer high numbers of buttons to a container. Scoring is based on time and # of buttons.	U, B, D/B, T, I, C	Buttons, toothpicks, pipe cleaners, non-specific building materials
Floating Platform: transport	DC, D/B, T, I, C	Marbles, medium size

three marbles in a floating platform of water a distance without spilling the marbles. Scoring is based on time and height of platform		containers for water, non-specific building materials
Bajaj Challenge: transport passengers quickly and safely from one location to another. Scoring is based on weight of vehicle and time.	DC, D/B, T, I	Ping pong balls, wire for a zipline, non-specific building materials
Balloon Throw: launch a balloon the farthest distance. Scoring is based on distance and size of launcher.	B, D/B, T, I, C	Balloons, straws, non-specific building materials.
Understanding the problem (U), Brainstorming (B), Defining design criteria (DC), Design and build (D/B), Testing Solutions (T), Iteration (I), Creativity (C)		

Kit Deployment

The MSU Fall 2015 course consisted of 24 laboratory sections (Team Design) taught by graduate teaching assistants (TAs). There were 246 total teams of approximately 4 students each formed randomly by TAs. A kit containing the designated construction materials along with an instruction sheet (see Appendix A) were provided to each team. Teams were given 30 minutes to design, construct, test and optimize their launchers. A competition between teams followed with teams that launched balls the farthest being recognized with extra credit points for the exercise.

After analyzing the result of the first delivery of the Team Design exercise, several modifications and competition rules clarifications have been proposed by the TA staff for implementation in the Spring 2016 course. First, the number of competition attempts will be reduced from three tries to a single opportunity. Next, a fixed distance will be implemented so that all teams in all lab sections will compete from the same starting position. Also, the objective of the competition will be detailed so as to maximize the number of cups knocked down as opposed to the greatest distance from which cups were toppled. Finally, the kit components will be modified with a reduction in the number of rubber bands as well as an increase in the number of binder clips and clothes pins.

Students were surveyed as to their experiences with the Team Design Exercise. Results are displayed in Table 2. They were asked:

1. What is your major?
2. How long did your team spend on understanding the Team Design Exercise, including reading the assignment, talking with your team and clarifying the assignment with your lab TA?
3. How long did your team spend on planning the Team Design Exercise, including discussing the steps you planned to complete with your team, assigning roles and setting time limits?
4. How long did your team spend on brainstorming the Team Design Exercise, including ideation, sketching ideas and discussing ideas with your team?

5. How long did your team spend on building the Team Design Exercise, including the first or first few prototypes before you tested them?
6. How long did your team spend on testing the Team Design Exercise (the total time spent testing)?
7. How long did your team spend on iterating on the design of the Team Design Exercise (building and modifying your prototypes after testing them)?
8. How many prototypes did your team create to solve the Team Design Exercise?
9. Did your prototype successfully complete the Team Design Exercise objective?

Table 2: Post Team Design Exercise Student Responses

Questions	**# Responses**	**% of Responses**
Q1: Major		
Applied Engineering Sciences	44	4.7%
Biosystems Engineering	49	5.2%
Chemical Engineering	126	13.4%
Civil Engineering	60	6.4%
Computer Engineering	62	6.6%
Computer Science	158	16.8%
Electrical Engineering	72	7.7%
Environmental Engineering	35	3.7%
Materials Science & Engineering	17	1.8%
Mechanical Engineering	260	27.7%
Other	55	5.9%
Q2: Time Understanding TDE		
1 minute	75	8.0%
2 minutes	220	23.5%
3 minutes	262	27.9%
4 minutes	108	11.5%
5 or more minutes	273	29.1%
Q3: Time Planning		
1 minute	114	12.2%
2 minutes	177	18.9%
3 minutes	232	24.7%
4 minutes	130	13.9%
5 or more minutes	285	30.4%
Q4: Time Brainstorming		
1 minute	92	9.8%
2 minutes	165	17.6%
3 minutes	192	20.5%

4 minutes	128	13.6%
5 or more minutes	361	38.5%
Q5: Time Building		
1 to 2 minutes	34	3.6%
3 to 4 minutes	118	12.6%
5 to 6 minutes	229	24.4%
7 to 8 minutes	256	27.3%
9 or more minutes	301	32.1%
Q6: Time Testing		
1 to 2 minutes	93	9.9%
3 to 4 minutes	192	20.5%
5 to 6 minutes	243	25.9%
7 to 8 minutes	163	17.4%
9 or more minutes	247	26.3%
Q7: Time Iterating		
1 to 2 minutes	118	12.6%
3 to 4 minutes	234	25.0%
5 to 6 minutes	265	28.3%
7 to 8 minutes	122	13.0%
9 or more minutes	198	21.1%
Q8: Number of Prototypes		
1	130	13.9%
2	433	46.2%
3	276	29.4%
4	56	6.0%
5 or more	43	4.6%
Q9: Successful Prototype		
Yes	831	88.7%
No	106	11.3%

Conclusion

We have developed kits capable of teaching students aspects of engineering design using hands-on activities rather than passive learning techniques. We have already deployed one of these kits in a freshman engineering class. The first kit tasked student teams to create a ping pong ball launcher with limited materials. This first kit addressed the following steps of the engineering design process: brainstorming, design/build, testing, iteration, and general creativity. Future plans for this kit are to use the challenge to evaluate student improvement in the understanding of engineering design process knowledge, learned in class.

The activities we have developed are worthwhile for instructors to adopt who are looking for short activities that can be rapidly deployed to teach and evaluate unique steps of the engineering design process. They could be useful in a laboratory or classroom setting. The challenges are team-based, which provides one of the major benefits of project based learning. Kits can be prepared quickly and simply as they are low cost and assembled from readily available materials. Successfully completing these challenges requires iteration and planning, skills that are germane to the engineering design process but difficult to teach. These rapidly deployable prototyping activities embrace active learning while also providing valuable hands-on experience with the engineering design process.

Bibliography

[1] ABET, "ABET Accredition Requirements," [Online]. Available: http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/. [Accessed 26 1 2016].

[2] J. S. e. a. Lamancusa, "2006 Bernard M. Gordon Prize Lecture*: The Learning Factory: Industry-Partnered Active Learning.," *Journal of Engineering Education,* vol. 97, no. 1, pp. 5-11, 2008.

[3] D. Knight, L. Carlson and J. Sullivan, "Staying in Engineering: Impact of a Hands-On, Team-Based First-Year Projects Course on Student Retention," in *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*, 2003.

[4] M. Prince, "Does active learning work? A review of the research," *Journal of engineering education,* vol. 93, no. 3, pp. 223-231, 2004.

[5] R. Bailey and Z. Szabo, "Assessing engineering design process knowledge," *International Journal of Engineering Education,* vol. 22, no. 3, pp. 508-518, 2006.

[6] G. C. A. S. C. J. L. a. R. C. Lemons, "The benefits of model building in teaching engineering design.," *Design Studies,* vol. 31, no. 3, pp. 288-309, 2010.

[7] J. a. B. A. Mackechnie, "Creative laboratory model for large undergraduate engineering classes.," *Journal of Professional Issues in Engineering Education & Practice,* vol. 138, no. 1, pp. 55-61, 2011.

[8] OEDK, "OEDK Innovate Challenges," [Online]. Available: http://oedk.rice.edu/innovate. [Accessed 26 1 2016].

[9] St. Louis University, "Weekly Innovation Challenges," [Online]. Available: http://parks.slu.edu/current-students/entrepreneurship-and-innovation/weekly-innovation-challenge/.

[10] W. M. Hinds T., "Workshop - Using Low Fidelity Prototyping Materials to Achieve Inexpensive, Rapid Development of Protoypes," in *First Year Engineering Experience Conference*, Roanoke, VA, 2015.

EGR 100 Introduction to Engineering Design

Fall 2015

Week 07 Team Design Exercise

Low-Fidelity Prototyping

Background: Low-fidelity prototyping is an inexpensive and effective means of developing an early version of a product to test and obtain consumer insight.

Task: The project will be conducted in lab with teams formed by the TA. Design a device to launch a ping pong ball and knock down a stack of plastic cups with the kit of provided materials.

Materials: 10 popsicle sticks, 20 assorted rubber bands, 2 each large, medium, and small binder clips, 2 clothes pins, and 1 ping pong ball.

Specifications & Rules:

1. Only the materials included in the kit may be used. This includes as many or as few of the materials as necessary.

2. Teams will be given 30 minutes to develop their ping pong ball launcher after which each must demonstrate in a competition.

3. The competition will determine the prototype that can knock down cups at the greatest range. Ten cups will be stacked and each team given three attempts to knock down these cups.

4. Teams that knock down all the cups will compete in successive rounds to determine the prototype that can knock down cups at the greatest range.

5. Teams are to attach their launcher to the table top as instructed.

6. Ping pong balls are to be fully supported only by the launcher (teams may not hold the ball in place prior to launching).

7. At the end of the exercise, the prototype must be disassembled and the materials returned to the TA as provided.

Grading: 2 pt - Launch a ping pong ball
2 pt - Knock down 5 or more cups
1 pt - Bonus for prototype that launches the farthest