Modifying a Pumping System in a First-Year Engineering Design Project

Amber Kemppainen, Namrata Jeason, Gretchen Hein
Michigan Technological University

Abstract

Creating design projects for first-year engineering students can be challenging. The material and projects must be presented at a first-year level of engineering knowledge while still remaining challenging, realistic, and interesting to students with varying backgrounds and engineering majors. Former students have designed, modeled, and constructed mousetrap vehicles, snowball launchers, or bungee jumps. These projects have been useful for introducing the design process as well as utilizing basic physics and math skills. Despite the complexity required for successful models, a major criticism for these types of projects is that many students have completed similar projects in high school.

At Michigan Technological University, instructors in the first-year engineering program are working to develop design projects and activities that relate to real-world issues and problems. With the development of the IDEAS Center (DUE-0836861), students are able to design, model, and construct projects that are directly applicable to engineering issues. Student teams working on IDEAS projects have developed and tested artificial legs and modified a pumping system for an aquaculture facility, the latter of which is the focus of this paper.

Introduction

An effective design project forges connections between course material and real-world engineering applications. At Michigan Technological University (Michigan Tech), instructors in the first-year engineering program received an NSF CCLI Phase I grant to develop design projects geared towards increasing these connections (DUE-0836861). As part of the IDEAS project, students enrolled in the first semester of engineering will complete the initial stages of research on a design. Their work (consisting of models, physical prototypes, and reports) will be provided to the next semester of engineering students where the project will be a continuation of the previous semester, but will include additional design constraints and complexity. This allows students to focus in-depth on one aspect of the engineering design, which permits the instructor to strengthen the connections between course material and the design project.

Louisiana Tech's "Living with the Lab" program is an example that uses this idea. Their three course engineering sequence builds on their experiences in each course in order to complete an open ended design project in their third course. In their first course (ENGR 120) students fabricate a centrifugal pump. This pump is used as a base for a fish tank project in their second semester (ENGR 121) where students control the temperature and salinity of a small volume of water. (Hall, Cronk, Brackin, Baker, & Crittenden, 2008, Hall, Baker, & Nelson, 2009, Crittenden, Hall, & Brackin, 2010) After one author attended a workshop in their facility in July 2009, the authors decided to develop a design project to incorporate the elements that could be duplicated at Michigan Tech.

This new aquaculture design project was developed for the two-semester engineering sequence for pre-calculus ready students (ENG1001 and ENG1100) (n=110). The overall design project for both semesters is to design, evaluate, and model an indoor Recirculating Aquaculture System. This system will be designed to raise fish from four to eight inches. In ENG1001, students will focus on the development and evaluation of the aeration system. In ENG1100, students focus on evaluating the pumps chosen for these systems as well as sizing and monitoring the facility. A pilot test of the ENG1100 material was completed in the spring of 2010 and this paper will focus on the initial implementation and results.

In past sections of the first-year engineering courses, students would often construct a physical model for their design projects. This physical model would be used to evaluate the overall design. For example, students created a harness for a bungee jumper or a mousetrap-powered vehicle that performed certain tasks. Following the physical model, students occasionally developed a 3D model using CAD software. This model was not required to be functional, only representative of the overall geometry of the designs. The pump project places a much stronger emphasis on good CAD modeling techniques and the importance of CAD in the design process. Students were required to use the CAD models they developed to evaluate their design projects.

UGNX Impeller Design and Manufacturing

A major portion of the ENG1100 project was the evaluation of the available (undersized) pumps and the design and manufacture of new impellers for the pumps. One of the differences between this project and the Louisiana Tech pump project is that our students only have the opportunity to manufacture the impeller. Another is that the student impellers must be compatible with an industrially manufactured pump, the Grainger 3P733. (Grainger, 2010) This submersible pump, Figure 1 below, could be placed inside or in-line with the tanks to cycle the water. An engineering drawing of the Grainger impeller with dimensions can be seen in Figure 2. The critical dimensions that the students must match are the center and key areas. If the students modeled these dimensions incorrectly, the impeller would not fit in the specified pump. Students had the freedom to research various impeller designs.

Once students decided on an impeller design, they created a 3-D model using UGNX 5.0. Students are introduced to UGNX 5.0 in ENG1001 and learn the basics of sketching with constraints. In ENG1100, students review this material and learn how to complete an associative copy. This is useful technique for creating the impeller blades as the students can sketch and extrude one blade and copy them about the center of the impeller to create the rest of the features. In addition, students are introduced to the drafting application so they can interpret the different orthogonal views presented to create the required critical dimensions and create an engineering drawing of their completed impeller for manufacturing.

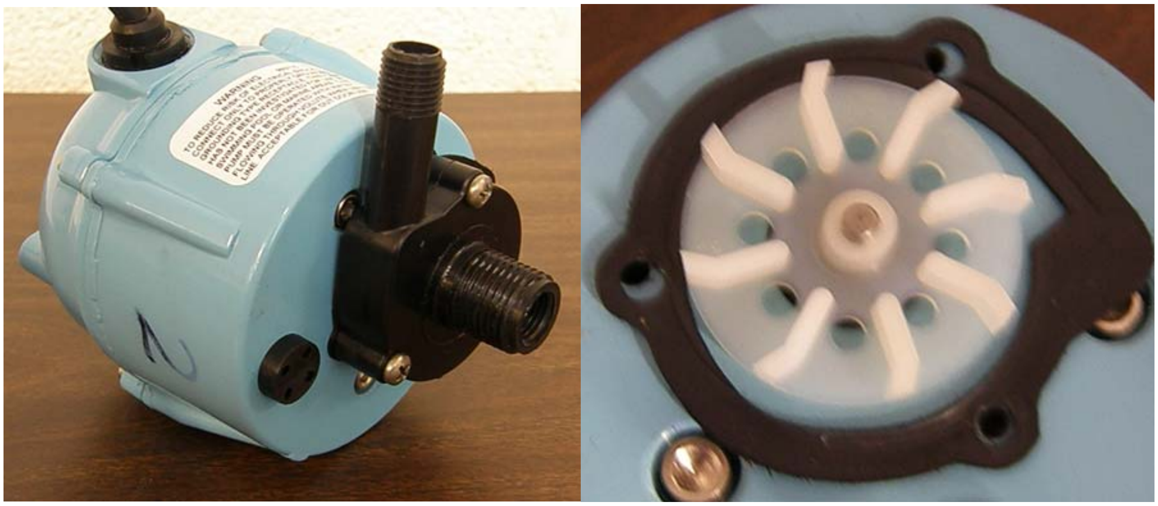

Figure 1. Grainger 3P733 Submersible Pump and Internal Impeller Configuration

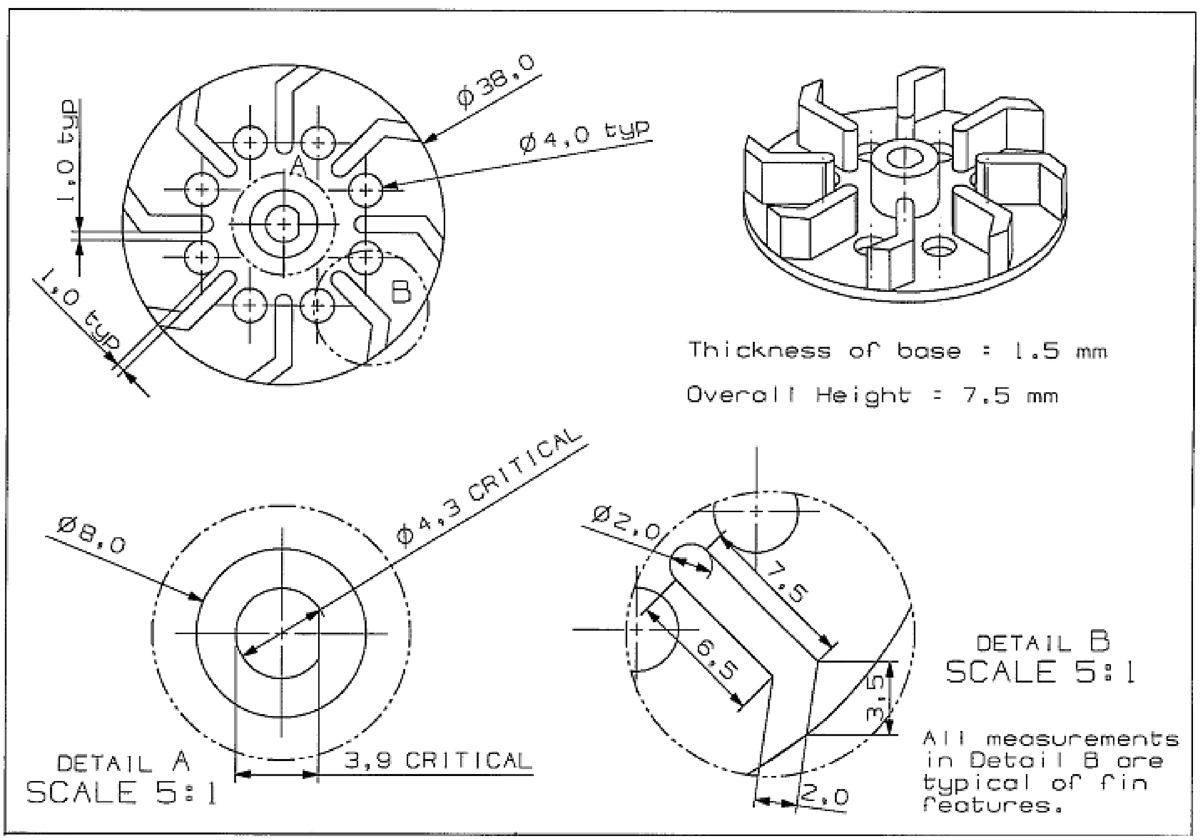

Figure 2. Engineering Drawing of Grainger 3P733 Impeller

An example of the typical process to design the pump impeller can be seen in Figure 3. Student groups traditionally begin by sketching and extruding the center and key mechanism (A), then follow with the base of the impeller (B). Sketching and extruding one impeller blade is the next step (C). Students then use the associative copy feature of UGNX to create an array of blades around the center of the impeller (D).

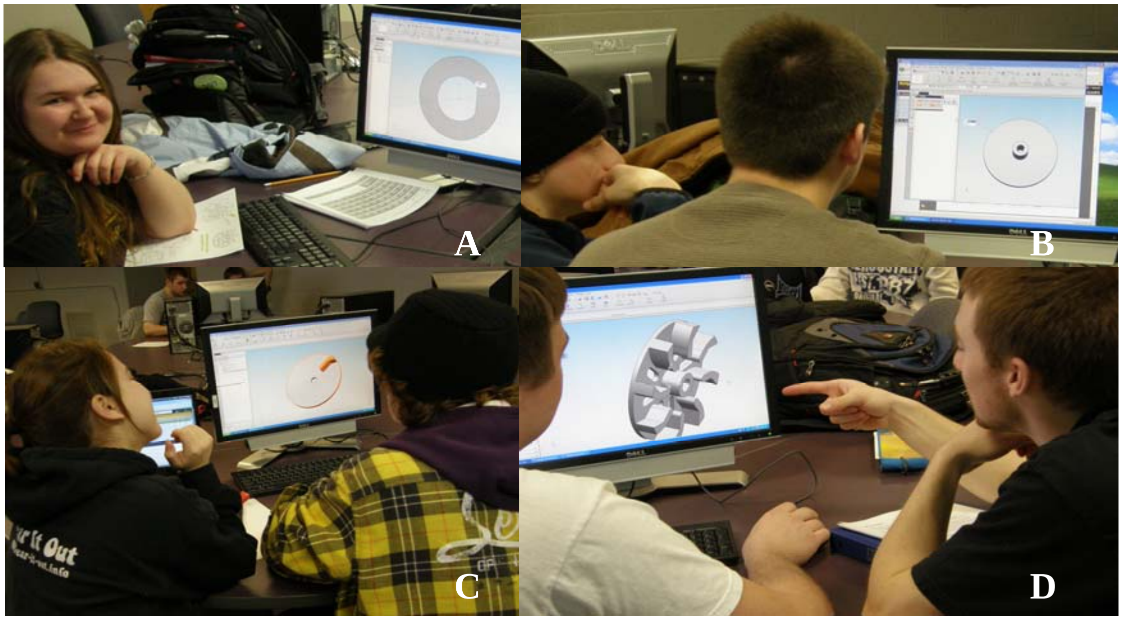

Figure 3. ENG1100 Student Teams Impeller Creation

Students use a variety of techniques when creating some of the impeller blades. Figure 4 shows some of the student designs. Many teams were satisfied by a simple sketch-extrude blade design. Several teams investigated using a tapered extrude to create a curved cup-shaped impeller or a beveled surface away from the center key area. Blades created in this fashion came to a very thin edge at the top and tended to chip easily. One team used a series of datum planes to create a lofted surface for the blade, again because of the irregularity and thinness of the surface, they seemed to wear quickly.

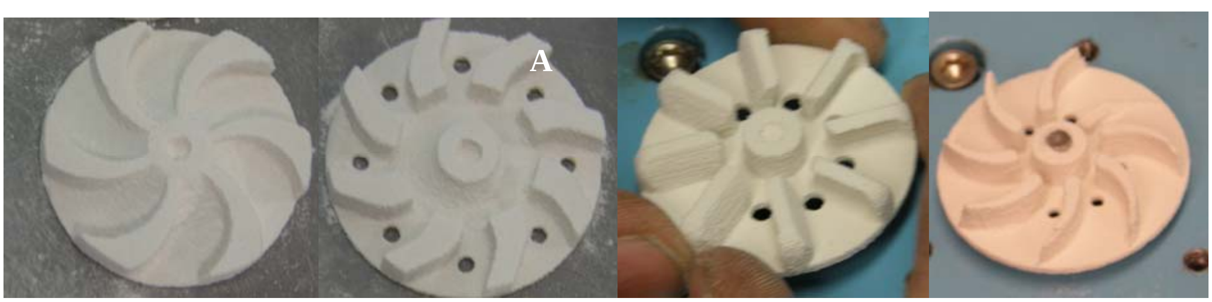

Figure 4. Sample of ENG1100 Impeller Designs

Once the impeller was complete, the file was exported to an .stl file and sent to the rapid prototype machine in the Materials Engineering Department. When the impellers were printed they were sealed using two different methods: a hot wax treatment or industrial epoxy. The hot wax was the fastest method sealing, and still allowed for some flexibility in “editing” the final shape, unfortunately these impellers tended to break if extreme care was not taken when installing them on the pump. The epoxy made a very solid impeller, however if teams did not meet the specified constraints, their impellers were not useable. In order to compare the performance of the Grainger impeller and their impeller, teams created pump characteristic curves in the IDEAS center for each design.

IDEAS Center Activities

The IDEAS Center was primarily used for gathering data for the pump and impeller analysis. In order to keep their fish tanks clean every four or so hours, each engineering group had to find out the maximum flowrate of their pumps at varying water heights. To do that, the pump analysis consisted of testing the mass of water the pump would eject depending on the height of the pump outlet tubing (from one to five feet in increments of a half feet) over a period of ten seconds. The tests were carried out with Tygon tubing, so changing the height was simple to do by folding or unfolding the tube in a circular manner.

To evaluate the impellers, each group installed their printed impeller into the pump and ran the same pump analysis test using this new impeller. For the impeller analysis, teams completed three trials for their impeller, and used the average data to compare with the manufacturer's data. Figure 5 shows one team's results. In this case their impeller performed better than the stock impeller used in the pump.

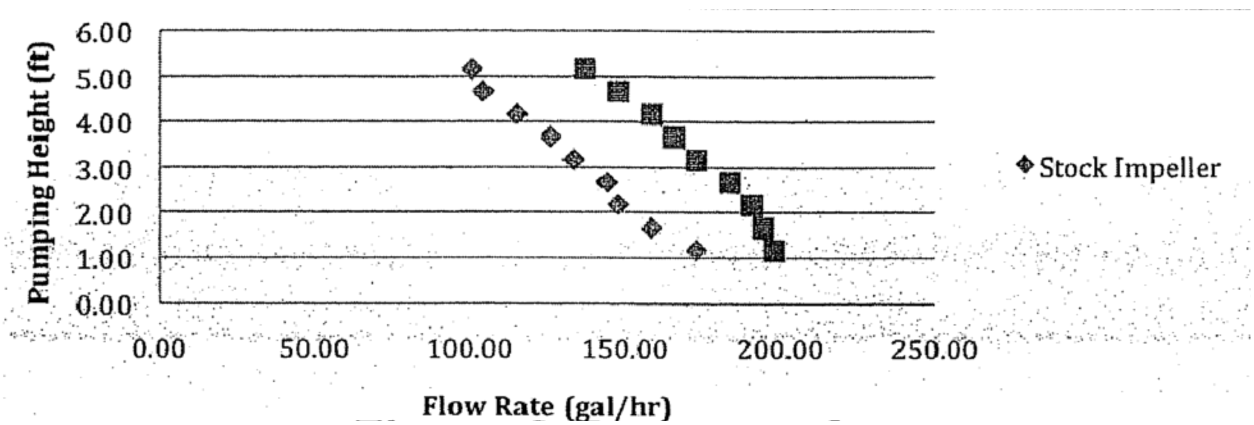

Figure 5. Example Pump Characteristic Curve for ENG1100 Teams

Major problems occurred during the beginning of the impeller analysis. Each group had their own unique impellers (a set of two in case one of the impellers broke) made out of a powdered ceramic and sealed with either wax or epoxy. On the first day of testing, the manufactured impeller was taken out so the new impellers were put into the pumps and lubricant was used to easily slide the impeller keyhole on the key of the pump. Many groups found that when pumping at lower heights, the pumps were working nicely, but as the height levels increased, the pumps would slow down or would not work at all. After opening the pumps to see the condition of the impellers, it was very noticeable that the impellers had broken. Two common issues for this were that the keyhole of the impeller would smooth out (typical failure for a wax-coated impeller), or the entire keyhole would break apart (failure for the epoxy-coated impeller).

Three trials were needed for a statistical analysis on the impellers, but several groups had had both impellers that broke early on, so they had to work with however many trials they had finished (sometimes being less than one). After realizing that the new impellers were fragile, certain steps were taken to ensure that the groups would finish all three trials. As soon as groups started pumping at heights close to five feet, they would take short breaks between pumping to ensure the impellers did not fatigue and round out the keyholes. One group in particular had received an impeller where the keyhole diameter was too small to fit around the key. Being in the IDEAS Center, they developed an idea of using a drill bit, approximately the size of the key, and scraped the impeller keyhole to increase its diameter. Their idea worked and the impeller was useful for all three trials. Regardless of these major issues, the students used their knowledge to overcome them and used whatever data they had acquired to finish their design project.

Focusing more in depth on the pump and impeller analyses, there were a few problems that had occurred while performing the tests in the IDEAS Center, some more significant than others. The minor issues while conducting the tests were a few water spills and inaccurate but precise masses for the amount of water pumped at various heights, which contributed to high standard deviation in the data. These issues however did not deter the overall results that the students needed as the average data corresponded well with the manufacturer's data. As a "lab" setting, the IDEAS Center is the ideal place to conduct these tests because the room itself is equipped with tools, such as mass balances, centrifugal pumps, power tools, sinks, and mops, so the experiments were under control and spills were handled properly. Mandatory usage of goggles and appropriate clothing helped save many students from being drenched, although it was not entirely preventable. Due to holding the Tygon tubing at each height by hand, many students faltered and angled the folded tube instead of keeping it level. This changed the height at which the water dripped out and gave a few inaccurate results as previously discussed.

Sizing the Aquaculture Tanks

Once the data were collected for both the stock and designed impellers, the students used the pump characteristic curves to determine the ideal size of the aquaculture tanks in their facility. For a given flowrate, teams were able to calculate the maximum height of the water in the tanks using their pump characteristic curves. For example, a student wanting a 1000 gallon tank 10 feet in diameter could calculate their flowrate by taking the total volume of the tank (500 gal), multiplying by 0.90 (90% working volume) and dividing by four (cleaning cycle time) to calculate an hourly flowrate of 112.5 gallons. Referring back to Figure 5, this gives an ideal height of the tank of approximately four feet for the Grainger impeller and almost six feet for the designed impeller. A faster flowrate means that the tanks can be larger, hold more fish, and produce more profit for their facility. Once students calculated their ideal tank size, students created a floor plan of their facility using UGNX. An example is shown in Figure 6 below. This team created an aquaculture facility with a series of 20 tanks, three feet tall and six feet in diameter. The tanks are elevated on a three foot platform to install and maintain the piping and pump system in the facility.

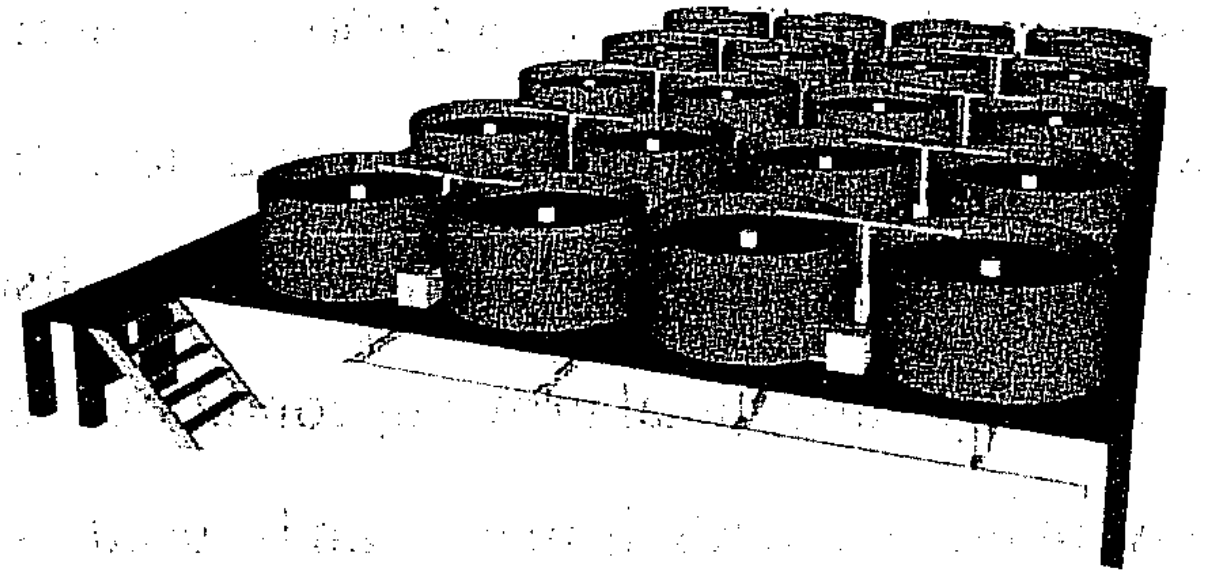

Figure 6. Example Floor Plan for ENG1100 Aquaculture Project

Student Feedback

On the subject of the design project, there were mixed feeling from the students. The most common complaints from the students were about the material used to make the new impellers. They thought it was too fragile and the keyhole could break easily in the water. Even with these issues, the students knew that the entire point of having new impellers was to improve and maximize their pump efficiency curves. However, those were not the only views the students had. A few students thought the aquaculture facility project had too many constraints for the size of the fish tanks, while others thought the project was a bit vague and could have had more constraints. Students who had never done an assignment like this in high school really liked working on the aquaculture project. One student found the design process of planning out deliverables and meeting times to be efficient and organized because he could follow the project from beginning to the end. In addition, initial results from IDEAS project surveys indicate that the 86.5% of students would like to see more interactive design projects in the first-year engineering courses that combine physical testing, modeling, and design.

Conclusions

The IDEAS Center and aquaculture project helped students better understand how pumping systems work and how to manipulate aspects of pumps in order to improve their indoor fisheries. The use of CAD modeling in this project allowed students to realize the importance of good CAD modeling techniques in the design process. Students created a functional CAD design that was tested in a pre-manufactured pump. Overall students thought the project was challenging and fun, especially when they used UGNX to design the impellers. Issues regarding the stability of the impellers will be addressed for future offerings of the course.

References

Crittenden, K., Hall, D., & Brackin, P. (2010) *Living with the Lab: Sustainable Lab Experiences for Freshman Engineering Students.* Proceedings of the 2010 American Society of Engineering Education Annual Conference. Louisville, KY.

Grainger Industrial Supply (2010). *Information for the 3P733 Submersible Pump* Retrieved from www.grainger.com on March 8, 2010.

Hall, D., Cronk, S., Brackin, P., Baker, M. & Crittenden, K. (2008) *Living with the Lab: A Curriculum to Prepare Freshman Students to Meet the Attributes of The Engineer of 2020*. Proceedings of the 2008 American Society of Engineering Education Annual Conference. Pittsburgh, PA.

Hall, D., Baker, M., & Nelson, J. (2009) *Living with the Lab: Update on the Second Year of Full-Implementation for over 400 First-Year Engineering Students*. Proceedings of the American Society of Engineering Education Annual Conference. Austin, TX.