Work in Progress – Rising to the Challenge: Revising a First-Year Engineering Course Around the Grand Challenges for Engineering

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Abstract - **Downward trends in the number of college students selecting STEM majors and graduating in those fields prompted a number of efforts to reverse the trends and student retention is a key measure of success. First-to-second year retention has been declining in our program over the last few years. Hands-on projects with connections to practical disciplinary application, community-building, and transformative first-year experiences are known to aid in improving student retention. One of the expected outcomes of our introductory course is to "Recognize contemporary and historic engineering issues and technological advances, and their impact in a global, economic, environmental, and societal context." The National Academy of Engineering Grand Challenges for Engineering provides a framework for helping students to explore contemporary issues and societal needs. This work explores the incorporation of several small scale hands-on projects related to the Grand Challenges for Engineering. Preliminary data indicates that this approach enhances student retention.**

Index Terms – First-year, Hands-on, Grand Challenges, Retention

MOTIVATION

The 2012 President's Council of Advisors on Science and Technology report identified a need for one million more Americans graduating with STEM degrees over the next ten years in order for the United States to meet the projected workforce demands [1]. However, there is widespread skepticism that this is attainable given recent statistics and trends on STEM attrition [2]-[4]. In response, numerous calls have been made to increase student retention. In fact, the American Society for Engineering Education (ASEE) launched a retention task force [5].

ASEE released a report outlining "best practices for retaining engineering, engineering technology and computing students" [5]. In that report, four of seventeen schools cited use of projects integrated into classes as one of their curriculum and class enhancements to improve retention.

Additional examples of enhancement in student retention due to the integration of projects into introductory or first-year engineering classes may be found in the literature [6]-[8]. In the examples cited above, a variety of reasons for the enhancements were identified. Canfield et al. found that hands-on projects made early disciplinary learning a more positive experience, improved confidence in learning engineering, and encouraged students to continue studying engineering. Kvam argues that active learning techniques like hands-on projects particularly benefit average students by providing the additional support beyond traditional lectures they need to be successful. Knight et al. used open-ended, self-directed hands-on projects and found particular retention enhancements for female and minority students due to heightened development of skills and intellect, strong sense of community and peer support, enriched mentor relationship with instructors, and improved attitudes about engineering.

The National Academy of Engineering (NAE) assembled a panel of expert engineers in 2006 to "identify a set of challenges faced by humankind in the 21st century that engineering has a role in solving" [9]. The resulting set of challenges was not intended to be a comprehensive list of the engineering needs and goals, but rather "opportunities that were both achievable and sustainable to help people and the planet thrive" [10].

These challenges seemed to provide a perfect framework for these authors to tackle two important goals related to first-year students: ensuring that all learning outcomes are addressed and improving retention. A campus-wide writing initiative prompted a critical review of the learning outcomes for the introductory engineering course. That process revealed a weakness in the coverage of contemporary issues and societal needs. Second, the authors had observed a decline in student retention from the first year to the second year over the last five years and, based on the literature, sought a thematic hands-on approach to enhance student retention.

OVERVIEW

The Dual Degree Engineering Program at Elon University is a unique blend of a liberal arts education and a traditional engineering education. The program mission emphasizes the development of broadly educated, contributive, world citizens.

Challenges in Engineering (EGR 103) is the required first-year course intended to teach incoming students about the engineering profession, the engineering design process, and the basic tools employed by engineers to design solutions to problems. The course is taught over two semesters with a major comprehensive team project highlighting each semester.

This paper focuses on the implementation of and retention outcomes observed in a preliminary investigation of the inclusion of several smaller hands-on projects based on the National Academy of Engineering Grand Challenges for Engineering.

IMPLEMENTATION

Students began the course with a traditional unit to explore the major engineering disciplines and the path to professionalism. They were then introduced to the NAE Grand Challenges for Engineering through traditional lectures and deepened their study of six of the fourteen Grand Challenges through the hands-on activities briefly summarized here.

The authors developed modules to explore the following Grand Challenges: Provide Access to Clean Water, Enhance Virtual Reality, Restore and Improve Urban Infrastructure, Reverse Engineer the Brain, Advance Health Informatics, and Make Solar Energy Economical. Each module grew in complexity to move the students from learning how things work to designing experiments to inform engineering design decisions.

I. Provide Access to Clean Water

Student teams were challenged to build an effective water filter using an assortment of provided materials, including sand, coffee grounds, carbon, and aquarium gravel. The instructors prepared water samples with a variety of pollutants to push them to think deeply about their choices of filtration materials and to help them gain a deeper appreciation for the difficulty removing pollutants from water. Students also tracked their water usage for a day to determine their water footprint. In a reflection exercise, they were challenged to think of ways to reduce their water consumption.

II. Enhance Virtual Reality

To gain an appreciation for the potential uses of and ways to improve virtual reality, students were given the opportunity to experience and compare Google Cardboard and Oculus. The original plan was for students to have the opportunity to observe engineering designs from the inside out, but engineering-related apps are currently limited. Therefore, a colleague who is very knowledgeable about virtual reality instead gave an interactive demonstration of the technology. Students also gained an appreciation for the importance of sensors in making virtual reality devices work by collecting and analyzing accelerometer data.

III. Restore and Improve Urban Infrastructure

Bridges are a key component of urban infrastructure and because students can relate to them easily, they were the focus of these activities. First, students were given a statics-themed introduction to trusses and explored compressive and tensile forces using the West Point Bridge Designer program. Next, students designed, constructed, and tested balsa wood truss bridges to support a static load at the center.

IV. Reverse Engineer the Brain

For this Grand Challenge, students learned about some of the current devices and technologies that are being used to help patients in need, such as the bionic eye and prosthetics controlled by brain waves for paraplegics. Then, students explored neuron/muscle communication and were able to record neural impulses to analyze differences in male and female reaction times.

V. Advance Health Informatics

With so many devices and apps available to acquire personal health data, student teams used a few to measure heart rate. They then developed a testable hypothesis, designed, and conducted experiments to identify variations in the accuracy of the heart rate data.

VI. Make Solar Energy Economical

Using scaffolding, students developed an understanding of how solar cells work, the data driven nature of many engineering design decisions, and designed experiments to inform potential improvements to existing systems. The unit began with a visit to a local solar farm to learn how solar cells work, the day-to-day operations and maintenance requirements at the site, and the current state of the industry and technology. Next, students were given small silicon solar cells to explore how orientation and tilt influence the energy production and thus understand the configuration they observed at the solar farm. Last, teams were challenged to design their own experiments using the silicon solar cells and to build cuprous oxide solar cells to explore other factors that affect the performance of solar cells.

METHOD AND RESULTS

One of the expected outcomes in EGR 103 is to "Recognize contemporary and historic engineering issues and technological advances, and their impact in a global, economic, environmental, and societal context." In a comprehensive review of the learning outcomes for the first-year course, the authors realized that the course content fell short in addressing the previously mentioned learning outcome. We believed this was a missed opportunity to expose students to possible career pathways and tap into the appeal of engineering being on the cutting edge of the discovery of ways to make life better. The NAE Grand

Challenges for Engineering provides a framework for helping students to explore contemporary issues and societal needs. In the process of developing the modules described earlier, we focused on incorporating exercises to help students develop problem solving skills and ways of thinking essential for success in the profession.

Retention data was collected over the last five academic years, beginning with students entering college in the fall 2011 semester and is shown in Table I. The study sample only includes students who were just beginning their engineering study; therefore, non-engineering majors and students who took the course out of sequence (e.g., after taking other engineering courses) were omitted. The data set includes a total of 182 students. For this study, a student is considered retained if he/she completed the first-year course and completed the second-year course, Engineering Mechanics: Statics. The one exception is the 2015 data, which is instead based upon current pre-registration information for Engineering Mechanics: Statics scheduled to be taught this coming fall 2016 semester.

TABLE I
PERCENTAGE OF STUDENTS WHO COMPLETED THE FIRST-YEAR ENGINEERING COURSE AND CONTINUED THROUGH THE FIRST SEMESTER OF THE SECOND-YEAR

First Year	% of Students
2011	79.5
2012	53.3
2013	58.6
2014	42.3
2015	70.6*

* based upon current pre-registration information

CONCLUSIONS

The instructors feel that a hands-on approach to teaching first-year engineering students based on the NAE Grand Challenges for Engineering deepens student learning in the important areas of the development of problem solving skills and design thinking. The topics truly seem to resonate with the students as evidenced by frequent declarations that EGR 103 was their favorite course during informal conversations.

Based on current pre-registration information, substantial gains in student retention have been observed from the first year to the second year after implementing the hands-on projects related to the NAE Grand Challenges for Engineering. These tentative results support the current literature documenting improvements in student retention as a result of the integration of projects into introductory or first-year engineering classes. Naturally, this observed preliminary improvement must be confirmed once the fall 2016 Engineering Mechanics: Statics course enrollment has been finalized at the completion of the drop/add registration period.

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