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Lessons Learned from Fundamentals of Engineering

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Abstract:

This paper conducts an in-depth analysis of the transformative impact of the Fundamentals of Engineering course on first-year engineering students. This course is meticulously designed to cultivate essential skills and foster continuous improvement. Central to its ethos is the cultivation of an engineering mindset, proficient problem-solving abilities, and the development of professional conduct. The course curriculum encompasses a diverse array of activities aimed at providing students with a comprehensive understanding of engineering principles. These activities include rigorous technical writing exercises, polished oral presentation skills, practical application of computer tools such as MATLAB, and a solid grounding in fundamental statistical concepts. Each component is carefully integrated to promote experiential learning and hands-on application. Through a steadfast commitment to refining instructional methodologies and adhering to stringent standards set forth by accreditation bodies like the Accreditation Board for Engineering and Technology (ABET), the course ensures that students are well-equipped to confront the multifaceted challenges of the engineering profession with confidence and competence. This paper serves as a testament to the efficacy of the Fundamentals of Engineering course in nurturing well-rounded engineers who are poised to make meaningful contributions to their fields upon graduation.

Keywords: Fundamentals of Engineering, experiential learning, problem-solving, professionalism, MATLAB, Arduino, Solid works.

1. Introduction

Engineering design is defined as the communication of a set of rational decisions obtained with creative problem solving for achieving certain stated objectives within prescribed constraints. The role of design in an engineering curriculum is a key factor contributing to its success [1]. Engineering design projects provide students with a broad view related to the material presented in lectures. Through project-based learning, students are encouraged to assume responsibility for their learning experience and to shift from a passive to an active learning style [2].

Multiple active learning projects and hands-on activities are incorporated in our Fundamentals of Engineering course to provide an active learning environment to incoming freshman students. This course is required for first-semester engineering students at Fairfield University. A key factor is the heterogeneous nature of the students taking the course, namely, electrical, bioengineering, mechanical and undeclared engineering students [3].

One of the signature assignments is the “Walking on Water” (WOW) team-based design project challenge. Students form design teams by choosing their teammates and then learn the systematic design process and design verification methods. This introductory design experience culminates with a review and presentation of design and a technical report. This project forms a structured introduction to the implementation of principles of design and engineering methodologies, project management, and presentation skills. Teams must design a system that propels a single person (the “operator”) across the entire length of the school’s swimming pool with a walking or running motion entirely above water [4].

This Evidence-based Practice paper describes the development and implementation of the "Walking on Water" team-based design challenge and the results of the survey administered at the completion of this project.

2. Course Overview

As the number of first-year engineering students has been increasing, so has the need for experienced faculty. In order to accommodate this trend, the course is team-taught to allow for continuous training of new faculty, as well as to incorporate regular faculty feedback into the ongoing process of improvement. We continuously measure the effectiveness of the course including its annual improvements. The four sections of the course were recently taught by four faculty with the aid of four Teaching Assistants (TA) who previously took the course.

First-year engineering courses are subject to a variety of forces in defining their purpose. Each course goal has been carefully chosen *a priori* and linked to ABET accreditation aligned course outcomes. The goals of the course are: (I) Create a passion for engineering. (II) Develop an engineering mindset, problem-solving skills, and critical thinking. (III) Develop engineering professionalism. Each course outcome links to one of those goals. These outcomes, which are also linked to ABET defined student outcomes, are used to define and measure the success of each activity and learning module of the course. A process of continuous improvement of active learning techniques to achieve each course goal and demonstrate each outcome has resulted in the effective development of our first-year engineering students.

While WOW is intended to equip students with skills that are useful in a classroom setting, it is also intended to give students a glimpse into the real world. The project was designed to meet the following learning objectives:

Learning Objective 1: Learn to work in interdisciplinary teams.

Learning Objective 2: Learn about project and time management.

Learning Objective 3: Learn to identify, formulate and solve engineering problems.

Two signature assignments are used as primary performance indicators in course outcome attainment. Those are the short research paper (approximately two pages long) with its oral presentation (approximately five minutes long), and the team-based design challenge with its team presentation. These assignments are significant as they also replace traditional exams in the course. They weigh heavily in determining student grading, as well as outcome attainment.

3. The main components of the course

- *Discussion of the undergraduate engineering curriculum at Fairfield University:* Faculty guest speakers from each engineering department provided an overview of their engineering disciplines and job opportunities.
- *Individual Technical Writing:* The first major writing project was an individual technical writing (ITW) assignment. Each student selected the topic of his/her choice. This project's main objective was to demonstrate effective technical writing. The specific content was not important. Students were required to use several library resources. They referenced journal articles, technical books, and internet sources, and were required to demonstrate proper technical citation using the IEEE citation style. For most students, this was their first experience with technical writing. They quickly realized that it was different from the writing they had done before in high school English, history,

and other non-technical courses. Furthermore, they went through a writing revision process in which their paper went through three iterations of review: self, peer, and instructor review. All reviews were done prior to the final grading of the paper.

- *Individual Oral Presentation:* The second project, early in the semester, was an individual oral presentation (IOP) of the ITW paper. This project's objective was to demonstrate effective oral communication of technical content. A lecture focusing on effective oral presentation techniques was presented to demonstrate effective oral presentations. Students presented their IOP in the class.

- *Writing Assignments:* Writing assignments (WAs) were chosen as an assessment method to demonstrate students' improvements in technical writing. Individual writing assignments included topics ranging from "Explain how something works" to "Reflect on your speaking skills". Specific content was not as important as demonstrating mastery of writing skills. For example, the first writing assignment was: Understand the roles of engineers in different fields and different industries in a global, economic, environmental, and societal context. Students were asked to interview an engineer and to discuss these topics. It did not matter which field, role, or industry they investigated [5].

- The Arduino activities: involved both theoretical instruction and hands-on mini projects taught by the instructor and the teaching assistant. Students were introduced to Arduino's open-source hardware philosophy, basics, and programming language, and they were provided with shared kits containing the necessary components for the mini-projects. Prior to the start of the projects, a mini tutorial was taken in class to ensure that students are able to install the Arduino software (IDE) on their personal laptops, including help with board drivers and library installation. Learning was facilitated through hands-on project work, allowing students to gain a comprehensive understanding of the IDE and the important concepts associated with Arduino programming [2].

- Project Management: This component of the course introduced students to the fundamental principles and practices of effective project management. Covering the project lifecycle from initiation through to planning, execution, control, and closure, students learned how to apply project management methodologies, tools, and techniques to real-world problems. The curriculum emphasized critical skills such as scope definition, time and cost management, risk analysis, and team dynamics. Through case studies and group projects, students gained insights into leading projects successfully and the importance of communication and collaboration in the project management process.

- Machine Shop: The Machine Shop sessions provided a hands-on introduction to the fundamentals of manufacturing and fabrication processes. Students were taught safety protocols and the proper use of machinery including lathes, milling machines, and drills. The curriculum focused on developing a practical understanding of material properties, cutting tools, and machining techniques. Through guided projects, students applied these concepts to create physical parts, gaining invaluable experience in translating design concepts into tangible products.

- Introduction to MATLAB: Students were introduced to MATLAB, a high-performance language for technical computing. The curriculum covered the basics of MATLAB programming, including matrix and array manipulation, data visualization, and the use of built-in functions for complex mathematical calculations. Through practical exercises, students applied MATLAB to solve engineering problems, analyze data, and develop algorithms. This module aimed to equip students with the skills to utilize MATLAB as a powerful tool for engineering analysis and research.

- Introduction to SOLIDWORKS and 3D Printing: This course segment provided an overview of 3D modeling, design, and printing using SOLIDWORKS software. Students learned the principles of CAD (Computer-Aided Design) and how to create detailed 3D models and assemblies. The curriculum also introduced the fundamentals of 3D printing technology, including printer operation, material selection, and slicing software. Through design projects, students experienced the end-to-end process of designing a part in SOLIDWORKS and bringing it to life through 3D printing, highlighting the potential of rapid prototyping in engineering design.

Two signature assignments are used as primary performance indicators in the attainment of course outcomes. These assignments include the short research paper (approximately two pages long) with an oral presentation (approximately five minutes long), and the Team-based Design (TDP) challenge with a team presentation. These two assignments are significant and therefore replace exams and thus weigh heavily in determining the students' grades as well as outcome attainment.

4. Enhancements Implemented in the Fundamentals of Engineering Course

Over the past 13 years, the Fundamentals of Engineering course has become integral to introducing first-year engineering students at Fairfield University to their disciplines, encouraging the formation of peer learning communities, and acquainting them with essential engineering practices. This has included everything from integrated design and data management to ethical decision-making and collaborative projects. Student feedback has underscored the course's effectiveness in fostering connection, enhancing retention, and equipping students for further engineering studies. However, recognizing the fast-paced evolution in the engineering field, we recently undertook a comprehensive curriculum revision.

Key Updates to the Curriculum:

1. Adoption of the Flipped Classroom Model: By incorporating the Rise authoring app and the Blackboard Learn platform, we shifted to a flipped classroom model. This approach inverted traditional learning by allowing students to engage with interactive content at home, thus freeing up class time for active learning exercises that bolster critical thinking and problem-solving skills.
2. Introduction of Digital and Interactive Assignments: We expanded our curriculum to cover the societal impacts of technology through the CITI Program's Technology, Ethics, and Regulations training. Beyond just STEM topics, the course now includes entrepreneurship, project management, and sustainability. Students utilize project management tools like Trello and Slack and create their own videos and posters to showcase their projects, promoting a deeper engagement with technological innovation.
3. Service-Learning in Final Projects: We transformed the course's capstone project into a service-learning experience, which has not only helped students develop their communication skills but also positioned them as mentors and leaders within the community. This update has aligned with our goal to cultivate engineers who are prepared to contribute positively to society.
4. Semester-Long Design Projects: Transitioning to semester-long design projects from the beginning of the term encouraged students to apply and integrate course concepts continuously. Access to the new Engineering Innovation Center (EIC) and its Maker Space has been instrumental in providing hands-on engineering experiences, reinforcing the course's practical emphasis.
5. Utilization of Modern Communication Tools: The curriculum now incorporates modern communication platforms like Microsoft Teams and Dropbox, along with data visualization tools

such as Tableau, equipping students with vital skills for effective teamwork and professional presentation in a technological landscape.

The curriculum enhancements in the Fundamentals of Engineering course represent a significant stride towards aligning our educational offerings with the realities of modern engineering practice. These changes, spearheaded by a dedicated team of instructors, including the seasoned Dr. Belfadel and recent faculty additions, have revitalized the course, as evidenced by improved student outcomes and engagement. This proactive approach ensures our engineering program continues to develop well-rounded professionals equipped to navigate the complexities of the field. Detailed instructor biographies are provided in the course's appendix for further insight.

The revamped “Fundamentals of Engineering” course now incorporates a comprehensive skill set developed through practical application and engagement:

- **Problem Identification and Research Question Formulation:** From the outset, students are immersed in the global challenges and opportunities outlined by the 17 Sustainable Development Goals (SDGs) and the National Academy of Engineering's 14 Grand Challenges. This framework guides them in pinpointing specific issues to tackle and formulating pertinent research questions, enhancing their ability to articulate complex problems to a diverse audience.

- **Setting Objectives, Goals, and Constraints:** Students engage in defining the scope of their projects by considering a spectrum of factors including economic viability, social equity, and environmental sustainability. This exercise sharpens their ability to convey the significance of their work to varied stakeholders, emphasizing the multifaceted impact of engineering solutions.

- **Literature Review and Research Methodology:** A partnership with reference librarians equips students with the tools and knowledge to navigate academic resources effectively, fostering a deeper understanding of data integrity, source reliability, and ethical considerations. This foundation supports their ability to discern credible information and communicate their findings clearly to both academic peers and the general public.

- **Idea Generation and Refinement:** Through peer collaboration, students are encouraged to share and refine their ideas, leveraging the collective creativity and insight of their group to address the identified problems. This process not only fosters innovative thinking but also bolsters their problem-solving capabilities.

As a culmination of these activities, students are tasked with presenting their research in various formats, from written reports to visual posters, at the annual Fairfield Innovative Research Symposium. This event serves as a platform for showcasing their work to a broader academic community, including peers, faculty, and external stakeholders. Select projects with significant impact and innovation are further presented at regional and national conferences, highlighting the exemplary work of our students and the forward-thinking curriculum of our engineering program. This approach has significantly enhanced student engagement with the material, fostering a culture of active learning, collaboration, and leadership within the engineering cohort.

5. Conclusion

The comprehensive revision of the "Fundamentals of Engineering" course at Fairfield University embodies our commitment to not only meet but exceed the evolving standards of engineering education. By integrating a forward-thinking curriculum that emphasizes problem identification, objective setting, thorough research, and innovative idea development, we are preparing our students to navigate and contribute meaningfully to the complex, global challenges of the 21st century. The adoption of pedagogical strategies such as the flipped classroom model, service-learning projects, and the incorporation of modern communication tools, coupled with the engagement in active learning and peer collaboration, ensures that our students develop not only as proficient engineers but as well-rounded individuals with a deep sense of social responsibility.

Our curriculum's alignment with the Sustainable Development Goals and the Grand Challenges for Engineering highlights our dedication to producing engineers who are not just problem solvers but also change makers. The enthusiastic participation of students in the redesigned course, evidenced by their engagement in the Innovative Research Symposium and success at regional and national conferences, confirms the positive impact of these pedagogical changes. As we move forward, the lessons learned from this curriculum overhaul will serve as a valuable blueprint for continuous improvement and innovation in engineering education. Our experience underscores the importance of adaptability, interdisciplinary collaboration, and a commitment to ethical and sustainable engineering practices, ensuring our graduates are well-equipped to lead with integrity and ingenuity in their professional and personal lives.

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