122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #12888

Developing T-Shaped Professional Engineers through an Advance Energy System Course

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Introduction

Technology innovation moves at an exponential rate making it extremely difficult for engineering curriculum to educate students on all current developments. All over the nation instructors are given a limited set of time to cover a wide variety of topics while ensuring the next generation of professional engineers[1-3]. This constraint forces instructors to a discipline based education, sacrifices hands on experience and student engagement for textbook based notes and passive student learning[3-5]. Although students are trained in a professional engineering discipline, they lack the full understanding of the broader role that fundamental engineering principles play in other sectors of industry[3, 6]. As a direct result, innovation suffers and emerging engineering students are left with a skill gap which employers are limited by their resources to fill[4, 7-8]. Therefore, in order to fill gap and create the next generation of innovative engineering, universities must adjust current engineering curriculum and find a balance between engineering disciplines and practical experience.

Over the past decade many universities have adjusting curriculums to develop students into T- Shape professionals, professionals who are highly trained in a single discipline, but have the capability of communicating, understanding, and working with people from a variety of other areas[3-4, 9]. Figure 1 represents a diagram that clearly defines the qualities of a T-shaped

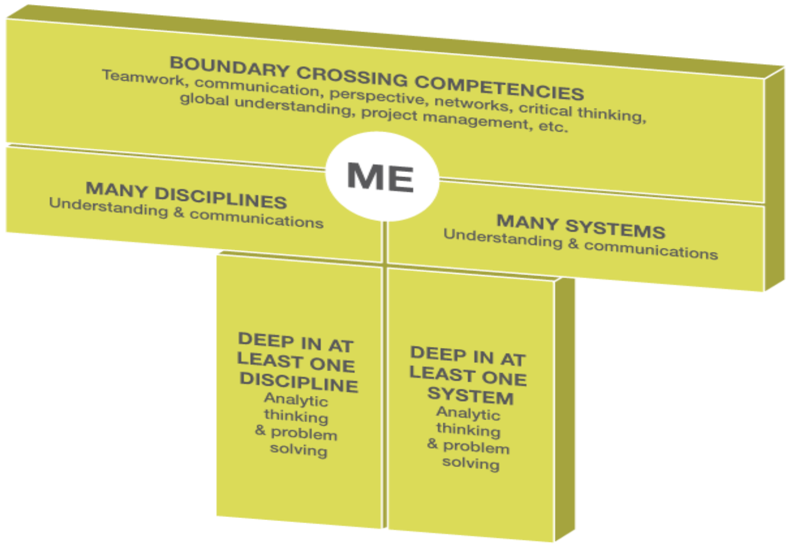

Figure 1: T-Shaped Professional Diagram from T-Summit 2015[9]

professional. The vertical bar represents the specialization of the single area (the students understanding of a detailed discipline) while the horizontal bar represents the boundary crossings into several different areas (the students understanding of many disciplines and systems and ability to communicate said understanding). Developing T-Shape professionals through an innovative curriculum would provide students with a major advantage in any competitive technical field. Although the idea of transforming an entire curriculum could encourage the development of T-shaped professionals on all fronts, it requires a significant amount of time and resources. However, small steps can be made to begin transforming engineering education by modifying individual courses.

This paper focuses on the development of Fuel Cell Science and Technology, a new innovative course that was designed to promote the development of T-shaped professionals through a reasonable balance of theory and practice. In order to develop a syllabus that focused on encouraging student curiosity and innovation, four basic principles were established:

1. Engineering education should not amount to the passive delivery of material. It should offer an active learning environment in which the students can build upon the knowledge gained from the classroom.
2. Engineering education is not only about quantitative analysis and technical skills, but also about synthesis, innovation, and gaining a holistic understanding of the impact of engineering activities on society.
3. The teaching of engineering should include useful problem solving tools and their application to a diverse knowledge base. Engineering students benefit from practice, using their newly found skills to address real-world problems.
4. Typical engineering problems are not solved with one area of knowledge; using teamwork is essential in engineering problem-solving.

Course Program

This course was intended to assist students in understanding and evaluating fuel cell systems and technologies, while also gaining a broader prospective of their influences and impacts from different perspectives. The majority of the eleven enrolled upper class students majored in Mechanical Engineering while the rest of the students majored in Aerospace Engineering. In order to ensure all the students could understand course topics, lessons were taught progressively, starting with a simple topic then building into more complex topics.

The course was divided into four portions: lecture, an interactive lecture series, lab sections, and final project lecture series. Lectures were held twice a week in a classroom setting and discussed fuel cell fundamentals. Table 1 shows the discussion topics such as fuel cell thermodynamics, electrode kinetics, performance and efficiency, transport process, classifications, fueling issues, and fuel cell systems and applications. During most lectures the technical challenges concerning the advancement of future fuel cell applications were also discussed. After seven weeks, students were given a midterm exam incorporating basic analysis of electrochemical and thermodynamic principles while including some response questions discussed earlier in lectures.

Table 1 Topics Covered in Fuel Cell Science and Technology

Lecture Discussion	Laboratory Experiments

- Introduction
- Basic Electrochemical Principles
- Thermodynamics of Fuel Cell Systems
- Transport Phenomena in Fuel Cells
- Performance Characterization of Fuel Cell Systems
- System Integration and Design
- Major Types of Fuel Cells:
    - Proton Exchange Membrane Fuel Cells
    - Direct Methanol Fuel Cells
    - Solid Oxide Fuel Cell
    - Molten Carbonate Fuel Cells
    - Phosphoric Acid Fuel Cells
	- Materials Synthesis and Characterization
	    - Slurry Preparation
	- Fabrication
	    - Dry-pressing
	    - Ball Milling
	    - Tape-casting
	    - Extrusion
	    - Ultrasonic Spraying
	    - Lamination
	- Performance Testing and Characterization
	    - Impedance Testing
	    - Current/ Voltage Measurement
	    - Fuel Ration Manipulation
	- System Integration

After the midterm exam, students participated in a three day lectures series covering topic such as fuel cell manufacturing, current industry practices of fuel cell technology, and fuel cell system design. Each lecture not only engaged students through open ended questions and key talking points, but also served as an introduction to other sections of the course. The first lecture, titled Current *Fuel Cell Manufacturing Techniques*, was led by a practiced research engineer and discussed various techniques of fuel cell fabrication methods. Students would later experience these techniques in following weeks during the lab sections. The second lecture was given by an experienced fuel cell engineer and was titled *Current Industry Practices of Fuel Cell Technology*. The lecture discussed current industrial systems and the major economic, political, and environmental policies influence on their design. Students would later be given an assignment exploring these topics in more detail. On the last day of the lecture series, students were given a preview of their final project. The last lecture, called *Fuel Cell System Design,* consisted of a brief overview of fuel cell system configurations and a step by step walk through of balance of plant design.

Figure 2: Students Participating in a Three Day Lecture Series

Before the lab sections began, students were divided into groups (two groups of four and one group of three). Each group would attend lab sections together and complete the final project at the end of the term. After they were divided, groups began preparing for the laboratory section by performing necessary safety evaluations and exploring various details of fuel cell fabrication and testing through reading assignments from current literature. The laboratory investigations were incorporated into the proposed course to offer students a more active learning environment, specifically the fundamentals of fuel cell systems covered in lectures. While in the lab, students performed fabrication, testing, and characterization of fuel cells in five laboratory sessions. This helped them observe the lecture material first hand.

During each section groups were given experiments to complete in the given class time. All experiments specified a fuel cell manufacturing process, as listed in table 1, which would examine a new configuration or classification of fuel cell technology. Moreover, hands-on laboratory experiments were a powerful way to encourage students to develop their teamwork skills. It has been well documented that teamwork can produce a superior outcome while giving students a sense of accomplishment, especially when the assignments are highly challenging[10]. Also, allowing students to work together greatly improved communication capabilities which can increases an engineer's effectiveness significantly[11].

During the lab section, all fabrication, configurations, and testing was conducted in a state of the art in the Combustion and Energy Research (COMER) laboratory, directed by Dr. Jeongmin Ahn[12]. This laboratory is equipped with a wide variety of instruments including an impedance analyzer, a provided computerized LabVIEW-based facilities for accurate partial pressure gas mixing and steady flow metering, and several chemical fume hoods,. This laboratory is also well equipped to fabricate solid oxide fuel cells (SOFC). The high temperature furnaces, pressing machines, stainless steel die, tape caster, laminator, oven with digital temperature controller, tabletop coating system with ultrasonic spraying system, piston extruder, and other supplementary equipment were all needed for the fuel cell fabrication. Also during the last lab session, the performances of fuel cells were tested using an available power source meter also running with LabVIEW.

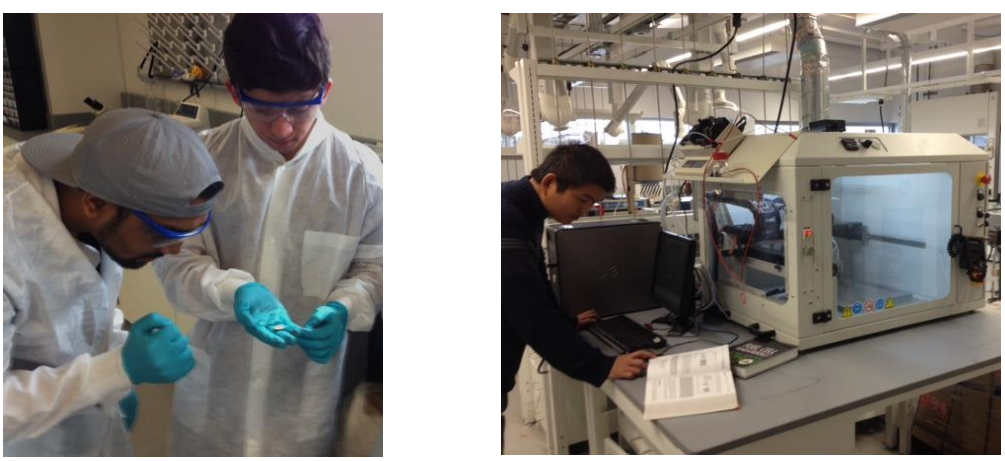

Figure 3: Students Working on Fuel Cell Lab Experiments

While performing laboratory experiments, groups were also assigned a weekly reading assignment. The assignment included a series of articles, suggested by the instructor then selected by the student, which provided different perspectives of fuel cell technology such as political, economic, and social/environmental. Each week groups had to select four articles that best represented the week's assigned perspective. After reading the article, groups were encouraged to have detailed discussion concerning what they had read and their own opinion on the matter. After discussing each article, students were required to write a one page response summarizing the article and linking it to the weekly assigned perspective. In doing so, the assignment was broadening student's perspective of fuel cell systems and disciplines in different areas while also encouraging students to communicate their understanding to others. After completing all the laboratory sessions, student were asked to write another response concerning fuel cell manufacturing techniques they experienced in lab and the role that process plays in industry.

For the last portion of the course, groups were expected to complete the final project: design a portable solid oxide fuel cell (SOFC) system. Groups were provided a set of design requirements and a pre-selected catalog of items used for their design. Groups were then expected to perform the proper calculations to find the optimal design while also discussing the broader impacts (political, economic, social, environmental, and manufacturing) of their design. Students would present their findings in a team presentation and submit a final report at the end of the semester.

In order to monitor student learning progress a survey was given at the beginning, middle, and end of the semester. The survey was designed to anonymously establish student retention of the information presented in lecture and lab, observe their progress in exploring different areas, and overall, summarizing there complete understanding of fuel cell technology. The survey asked students their thoughts of the understanding broader impacts, hands-on research experience, whether or not student's interest in science and engineering was increased and if the overall course generated a continuation in engineering fields. The answers ranged from strongly disagree to neutral to strongly agree on a scale of one to five.

Results and Discussion

After the course was completed, the data from the surveys was compiled and evaluated to see if the course had encouraged T-shaped professional and supported its founding principles.

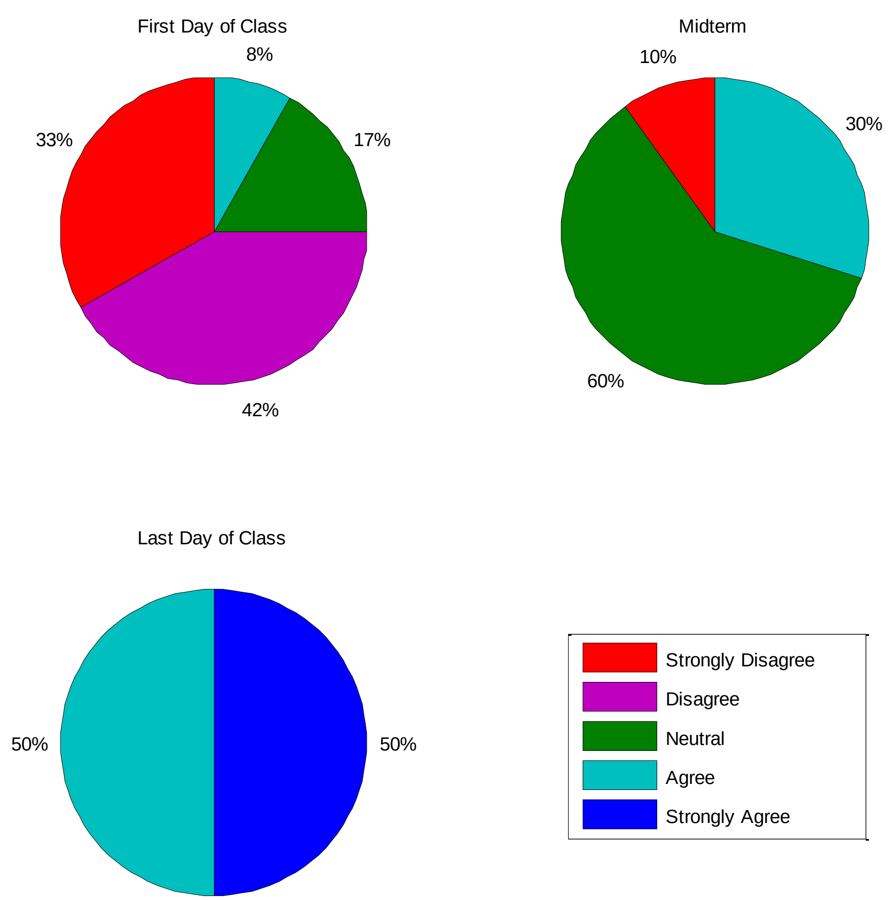

Figure 4: Survey Question "I know a lot about Fuel Cell Science and Technology"

The first question wanted to examine the progress of students understanding of the fuel cell discipline (i.e. the vertical component that begins to form a T-shape professional). It can clearly be seen that a majority of students didn't know much concerning fuel cell technology initially. However as the semester advanced, students comprehension of fuel cell fundamentals began to grow as seen in the figure above. At the end of the semester all of the students agree or strongly agreed that they had a strong comprehension of fuel cell science and technology.

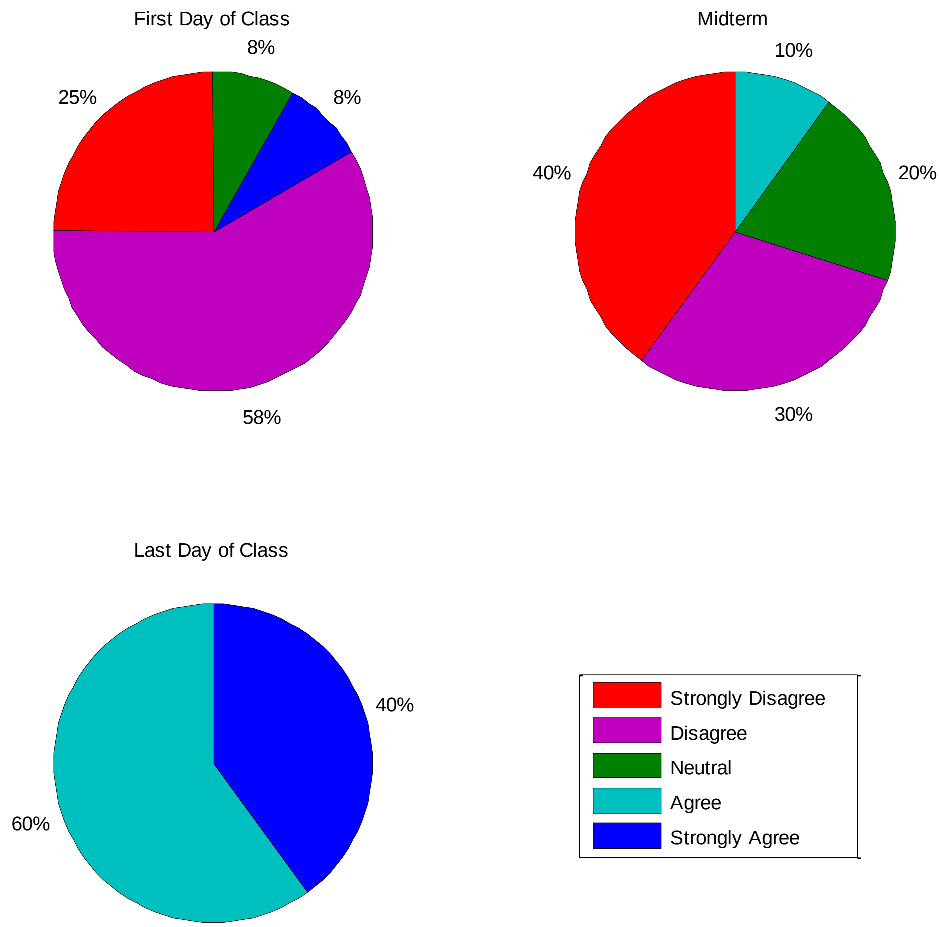

Figure 5: Survey Question "I have a strong understanding of the Political aspects concerning fuel cell technology"

Shifting focus from I professionals to T professionals, the next three survey questions asked whether or not students understood fuel cell technology's position in different areas (i.e. political, economic, social/environmental). For the first half of the semester students had little understanding of the broader impacts fuel cell technology had in different areas, with the exceptions of one or two students. At the final survey, after students completed the weekly assignment, there was a dramatic shift in student comprehension of broader impacts as seen in figure 5, 6, and 7.

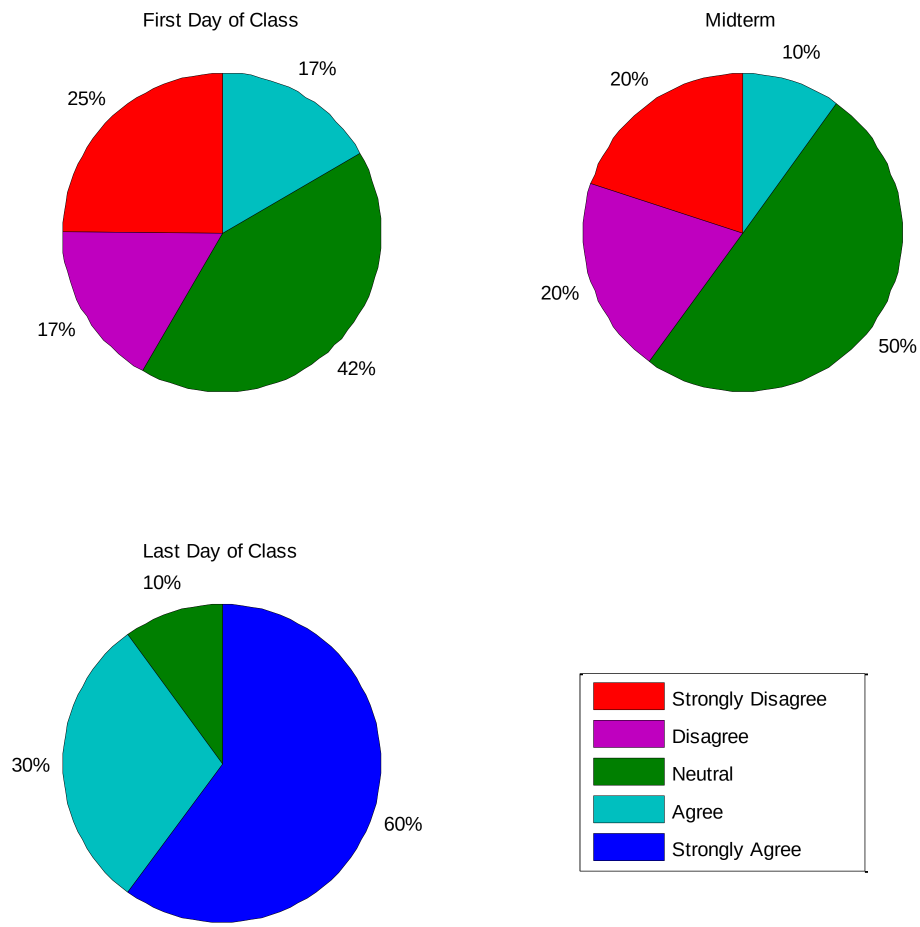

Figure 6: Survey Question "I have a strong understanding of the Economic aspects concerning fuel cell technology"

Student's broader understanding of fuel cell technology was not only seen in the surveys, but also in the final presentations and laboratory discussions. During the lab sections, students began to engage in thought provoking discussion concerning the various perspectives of fuel cell technology in different sectors of industry. Many discussion topics included policy changes that needed to be made to encourage alternative energy advancements, the cost of natural gas drastically affecting current fuel cell demand, and the possible advancements needed to secure the future of the fuel cell industry.

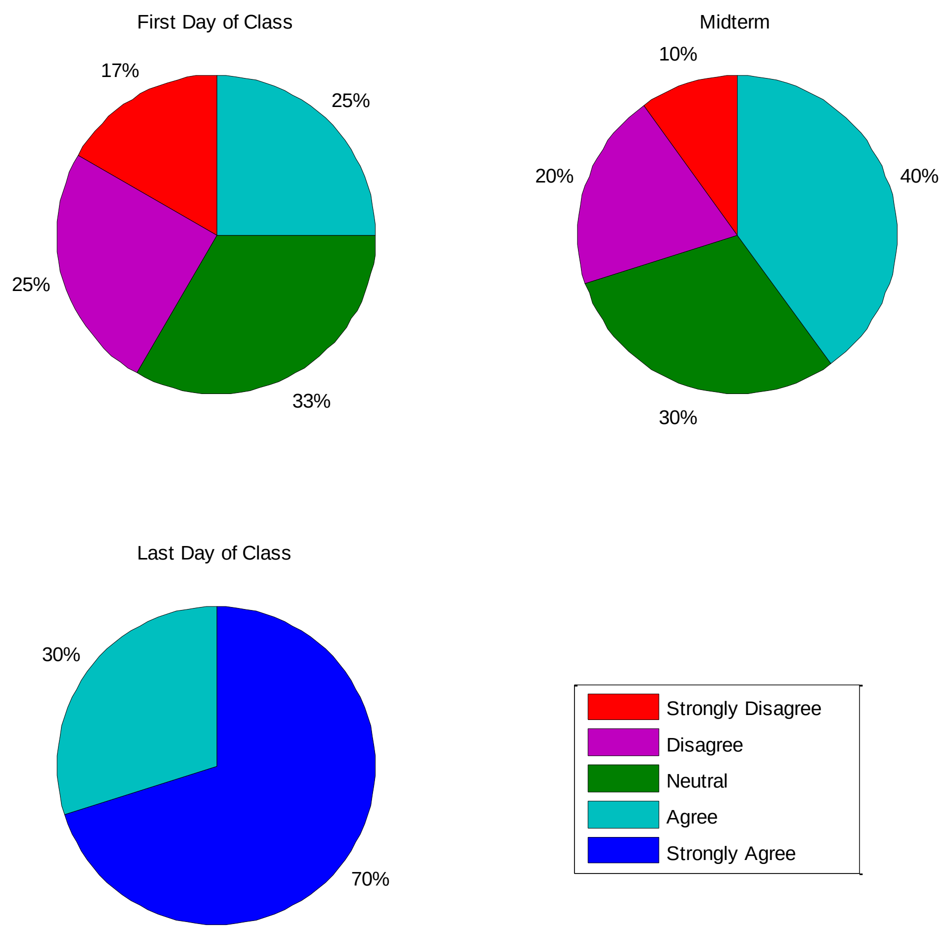

Figure 7: Survey Question "I have a strong understanding of the Social/Environmental aspects concerning fuel cell technology"

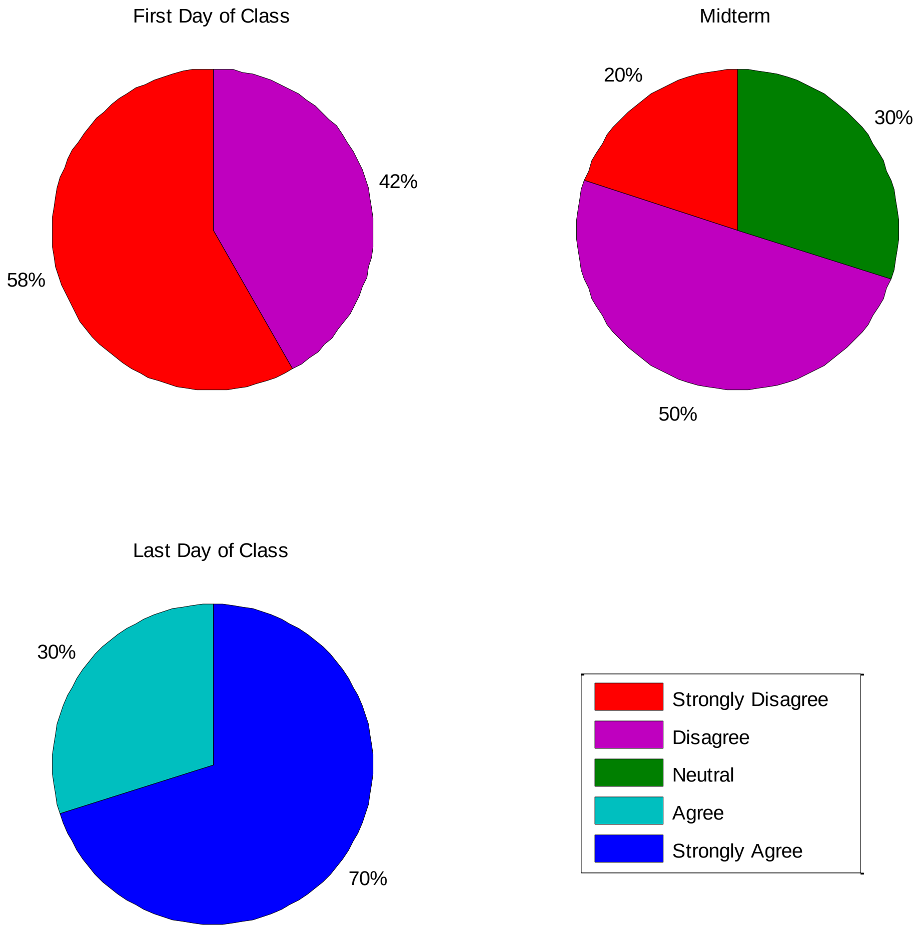

Figure 8: Survey Question "I have a strong understanding of the Balance of Plant aspects concerning fuel cell technology"

Looking more specifically at the final presentation criteria, students were asked to design a fuel cell system which would help them to better understand balance of plant strategy and provide real world application experience. As seen in figure 8, students' understanding of the practical fuel cell design increased significantly by the end of the course with all the students either agreeing or strongly agreeing that they understood balance of plant. This observation of growth was further solidified during grading when an experienced fuel cell system engineer claimed that each group's designs were just as good or better than a majority of entry level fuel cell engineer.

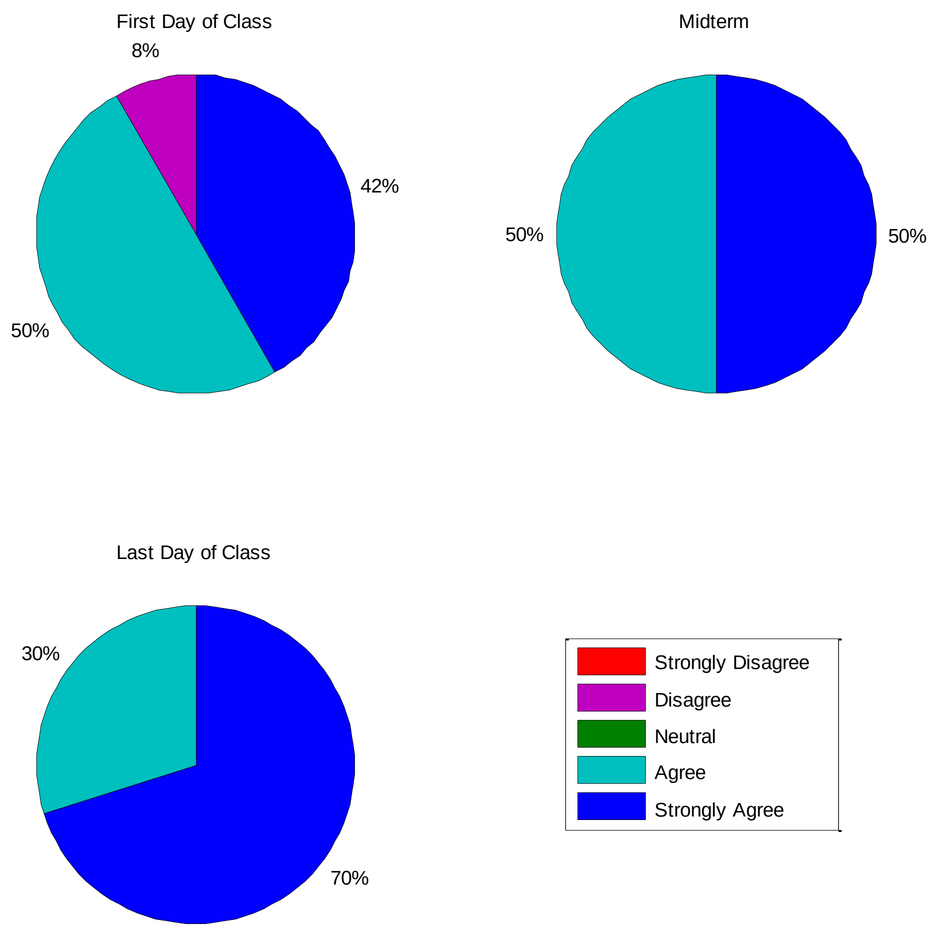

Figure 9: Survey Question "Hands-on laboratory experiments are powerful way to develop our teamwork skills and communication skills"

One of the important goals this course set out to achieve was to encourage strong communication between students. The surveys showed that overtime the majority of students strongly agreed that laboratory experiments had improved teamwork and communication skills. Additionally, this was demonstrated in the lab sections with many group working together to complete lab assignments. Many students showed creativity and good collaboration when faced with each weekly lab assignment. If there was one student that was struggling with a certain aspect of the lab, there was always another student who could explain the complex material showing good communication and teamwork skills.

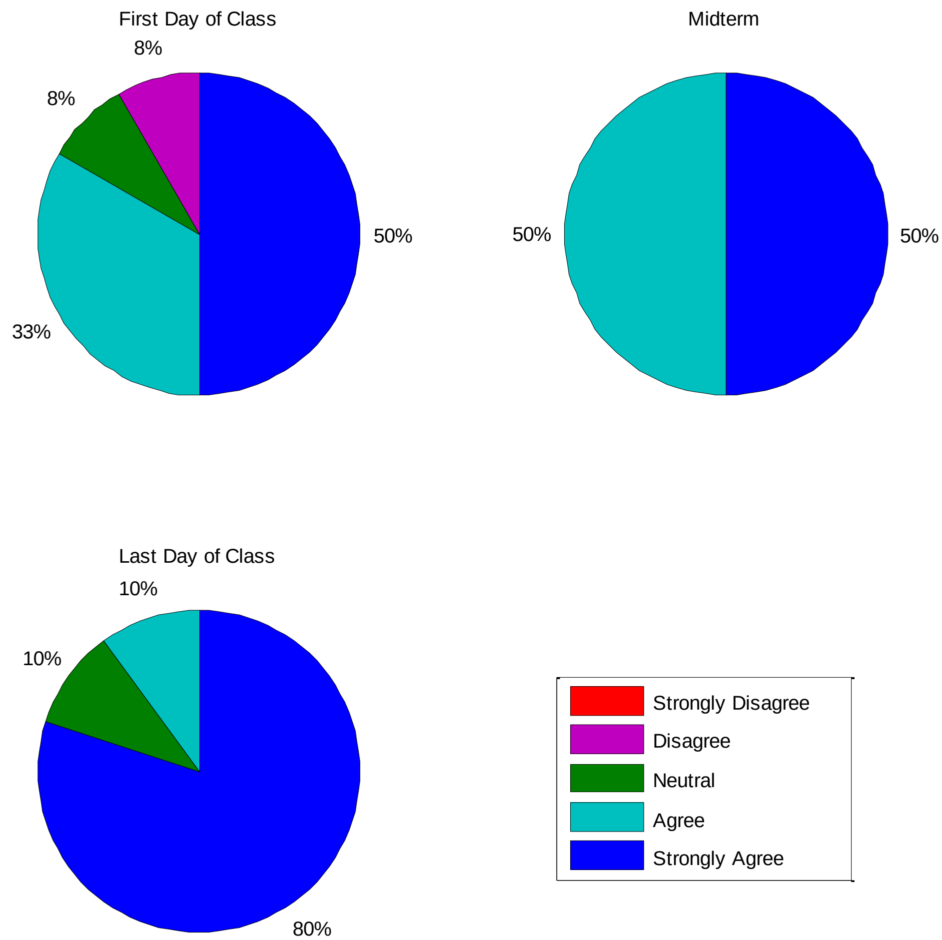

Figure 10: Survey Question "Hands-on laboratory experiments are a great way of reinforcing the concepts presented in lecture by building upon knowledge gained in lecture"

One of the last goals of this course was to reinforce the knowledge learned in lecture in the lab section, linking the single discipline of fuel cell fundamentals (vertical bar) with the wide span of multidisciplinary overlap into different areas (horizontal bar). Figure 10 depicts a gradual increase in the majority of students who strongly agreed that this goal was achieved, but there is a small portion of students who went from agreeing at the mid-semester mark to feeling indifferent at the end of the semester. It can be inferred that students might have felt indifferent due to disinterest towards laboratory experiments. Although lab experiments can be enjoyable for some, they might not be enjoyable for others. However, this gradual decline depicts the results from a small sample size and does go against the rest of the survey data.

Conclusion and Future Work

The Fuel Cell Science and Technology course contained a modified curriculum that encouraged T-Shaped professional skills through the focus on fuel cell fundamentals while also expanding on fuel cell technology's influence and role in different sectors of industry. The surveys used to monitor students personal investment in the course was increasing positive as the semester progressed. The final surveys also showed that the overall course provided students with a stronger confidence in their ability and a higher interest in alternative energy systems.

Due to the consistent positive feedback from students, the course succeeded in encouraging T-Shaped professionals from modifying the curriculum. Strong communication, teamwork, and deeper and broader understandings were some of the major skills that each student exemplified over the semester. Although, several milestones were achieved, it was impossible to cover fuel cell fundamentals, technology, and influence in different areas in their entirety due to the limited time. Each section, despite providing extensive detail, laid the foundation that students can be expected to build upon themselves either through individual teachings or group discussions. Students desire to continue the discussion of fuel cell topics, including 'industrial advancement in the next five years' or 'moving the U.S. to a hydrogen economy', signified that many students were eager to continue their investment in advance energy systems either in graduate school or industry.

Despite its small enrollment, this course indicates an initial step into a transformative engineering education system while demonstrating the feasibility of encouraging innovative critical-thinking engineering students. In many instances, many traditional science courses (Chemistry, Physics, etc.) already have a curriculum similar to this course: a lecture and with a lab section that reinforces class discussions. However, in those instructors focus heavily on fundamental material and less on the professional development of the student. Therefore, in order to apply this method to a wider basis, the initial change must begin with the instructors, who might be limited by their resources, but can teach creatively outside of the text book to reach a larger majority of students. Innovative teachers inside the classroom lead the way for future innovative engineers. In by doing so, more T-Shaped professionals will emerge, making it the responsibility of the faculty, administrators, and facility leaders to work together and gradually transform the curricula in its entirety, thus paving the way for a new generation of professional engineers and an exciting innovative future.

Acknowledgments

This work was partially supported by the Syracuse University College of Engineering and Computer Science Faculty Excellence Award and the National Science Foundation under grant CBET-1403405.

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