Developing T-Shaped Professional Energy Systems Engineers

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Abstract

A fuel cell science and technology course was created to promote the development of T-shaped professional energy systems engineers. The course structure consists of lectures as well as laboratory sections to reinforce principles discussed in class. Survey results conducted on the first day of class, at the midterm and on the last day of class show a trend towards increased student understanding of fuel cell science as well as the political, economic, social and environmental impacts of fuel cell technology. Hands-on experience during laboratory experiments as well as the fuel cell system design project helped promote T-shaped professional development of the students.

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 teach 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 a full understanding that links fundamental engineering principles and the broader role the engineering discipline plays 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 the 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 adjusted their curriculum to develop students into T- Shape professionals. A T-Shaped professional indicates one who is highly trained in a single discipline, but has the capability of communicating, understanding and working with people from a variety of other areas[3-4, 9]. Figure 1 clearly defines the qualities and skills required of a T-Shaped

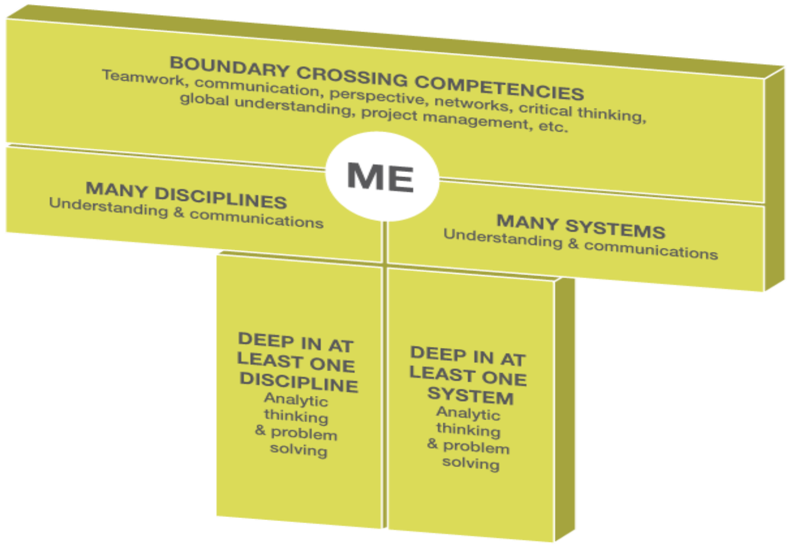

Figure 1: T-shaped Professional Diagram from T-Summit 2015[9]

professional. The vertical bar represents specialization in a single area (the student's detailed understanding of a discipline) while the horizontal bar represents breadth, with the boundary crossing 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. The qualities and skills associated with T-shaped professionals also corresponds too many of the skills needed in energy systems engineering, thus promoting T-shaped professional energy systems engineers. In order to develop a syllabus that focuses 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 perspective of societal, economic and political influences and impacts. The majority of the eleven enrolled upper class students majored in Mechanical Engineering with only 2 of the students majoring 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 a final project presentation 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, and fueling issues. During most lectures the technical challenges associated with fuel cells and their applications were also discussed. After seven weeks, students were given a midterm exam that required 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
- Combustion Reactions, Fuels and Oxidants
- Basic Electrochemical Principles
- Thermodynamics of Fuel Cell Systems
- Transport Phenomena in Fuel Cells
- Major Types of Fuel Cells:
    - Proton Exchange Membrane Fuel Cells (PEMFC)
    - Direct Methanol Fuel Cells (DMFC)
    - Solid Oxide Fuel Cells (SOFC)
    - Molten Carbonate Fuel Cells (MCFC)
    - Phosphoric Acid Fuel Cells (PAFC)
	- Materials Synthesis and Characterization
	    - Slurry Preparation
	- Fabrication
	    - Dry-pressing
	    - Ball Milling
	    - De-airing
	    - 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 topics 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 fuel cell manufacturing lecture, *Solid Oxide Fuel Cells (SOFCs)*, led by a practiced research engineer, discussed various SOFC fabrication methods. Students would later experience these techniques during the lab sections conducted in a laboratory that specializes in SOFC development. The second lecture was titled *Current Industry Practices of Fuel Cell Technology* and led by an experienced fuel cell engineer. The lecture discussed current industrial systems and the major economic, political, and environmental policies influencing 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 through a lecture entitled, *Fuel Cell System Design*. The last lecture consisted of a brief overview of fuel cell system configurations, basic componentry 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 randomly 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 and build upon the lecture material first hand.

During each section groups were given experiments to complete in the given class time. All experiments required students to learn a fuel cell manufacturing process, as listed in table 1. Moreover, hands-on laboratory experiments were a powerful way to encourage students to develop their teamwork skills, which are essential when working with systems that involve expertise from many different disciplines. 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 increase an engineer's effectiveness significantly[11].

All fabrication, configurations, and testing was conducted in a state of the art combustion and energy research laboratory. This laboratory is equipped with a wide variety of instruments including an impedance analyzer, 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 SOFCs. 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 fuel cell fabrication. The fuel cell performance was tested using an available power source meter running with Labview.

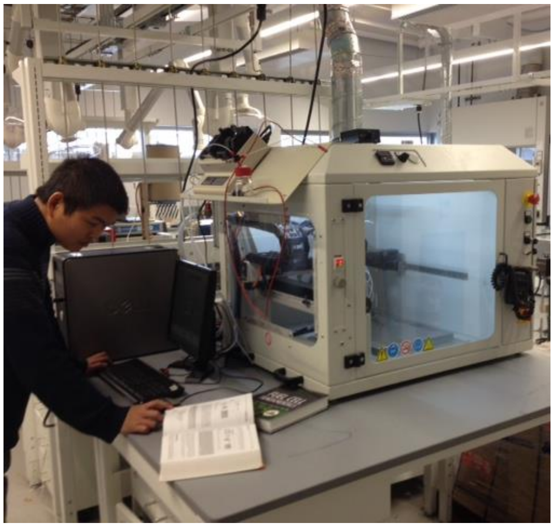

Figure 3: Students Working on Fuel Cell Lab Experiments

While performing laboratory experiments, groups were also assigned a weekly reading assignment and write-up by the instructor. The reading assignments were meant to broaden the student's perspectives on fuel cell technology. To do this, each week a different theme was chosen. The three themes were political, economic and social/environmental aspects of fuel cell technology. Each group was given the same set of 12 articles from which there were 4 articles related to political, 4 related to economic and 4 related to social/environmental aspects of fuel cell technology. The groups were instructed to divide up the articles so that each team member read a different article related to the weekly theme. After reading the article, groups were encouraged to have detailed discussion concerning what they had read and their own opinion on the matter. Finally, students were required to write a one page response summarizing the article and linking it to the weekly theme. In doing so, the assignment broadened student's perspective of fuel cell technology and systems in different areas while also encouraging students to communicate their understanding to others. After completing all the laboratory sessions, students were asked to write a fourth response concerning fuel cell manufacturing techniques they experienced in lab and the role these processes 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, a SOFC polarization curve for various operating temperatures and a pre-selected catalog of items and component specifications used for their design. Groups were then expected to perform the proper calculations to find a design that would meet the requirements. Further attempts to optimize the design were encouraged by requiring at least 3 design iterations. The design process also required students to perform an interdisciplinary analysis that moves away from their core curriculum. For example, the design required a strong understanding of Balance of Plant (BOP) components and how said components would be utilized in a SOFC system. In order to size the components, such as power electronics for power conditioning, students had to develop an understanding of the electrical components incorporated into their systems; a task that might have been easier for a student with an electrical engineering background. Furthermore, the process required proper heat and mass transfer analysis and balance, portions of which sometimes fall outside of the mechanical and aerospace discipline. At the end of the semester students would present their findings in a team presentation and submit a final report. Each group was asked to incorporate the broader impacts (political, economic, social, environmental, and manufacturing) of their design into their final presentation and report.

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, summarize there complete understanding of fuel cell technology. The survey asked students about their understanding of 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 development and supported its founding principles.

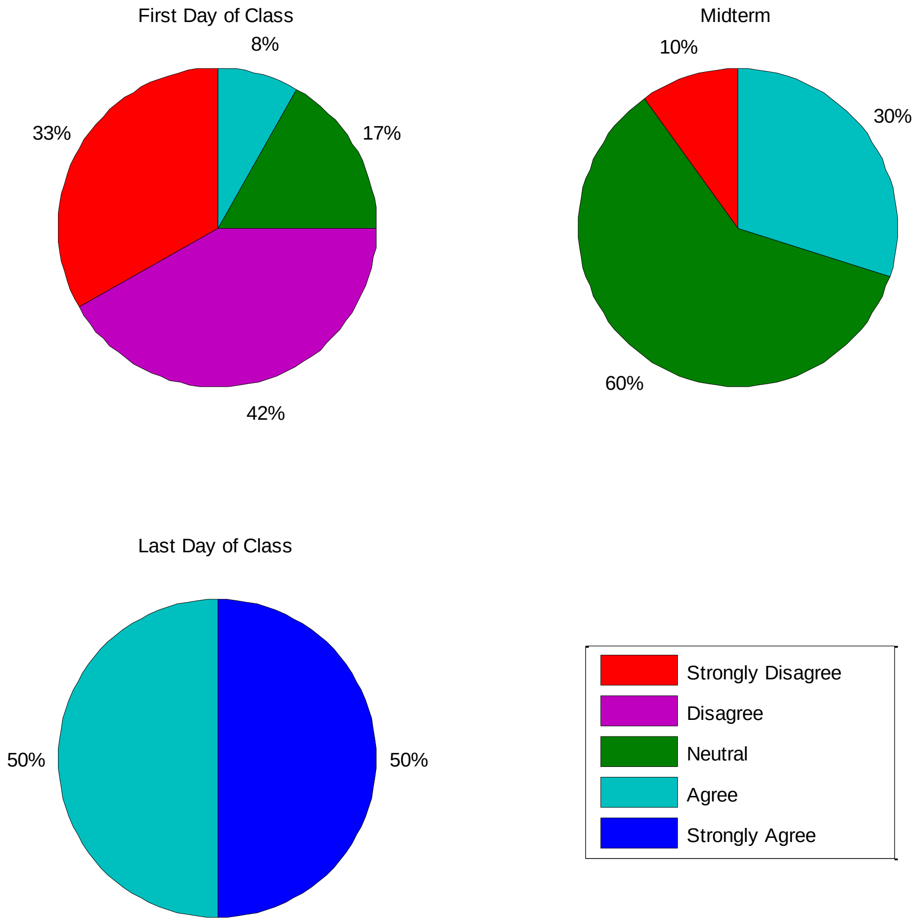

Figure 4: Survey Question "I know a lot about Fuel Cell Science and Technology"

The first question examined 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 about 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 agreed or strongly agreed that they had a strong comprehension of fuel cell science and technology.

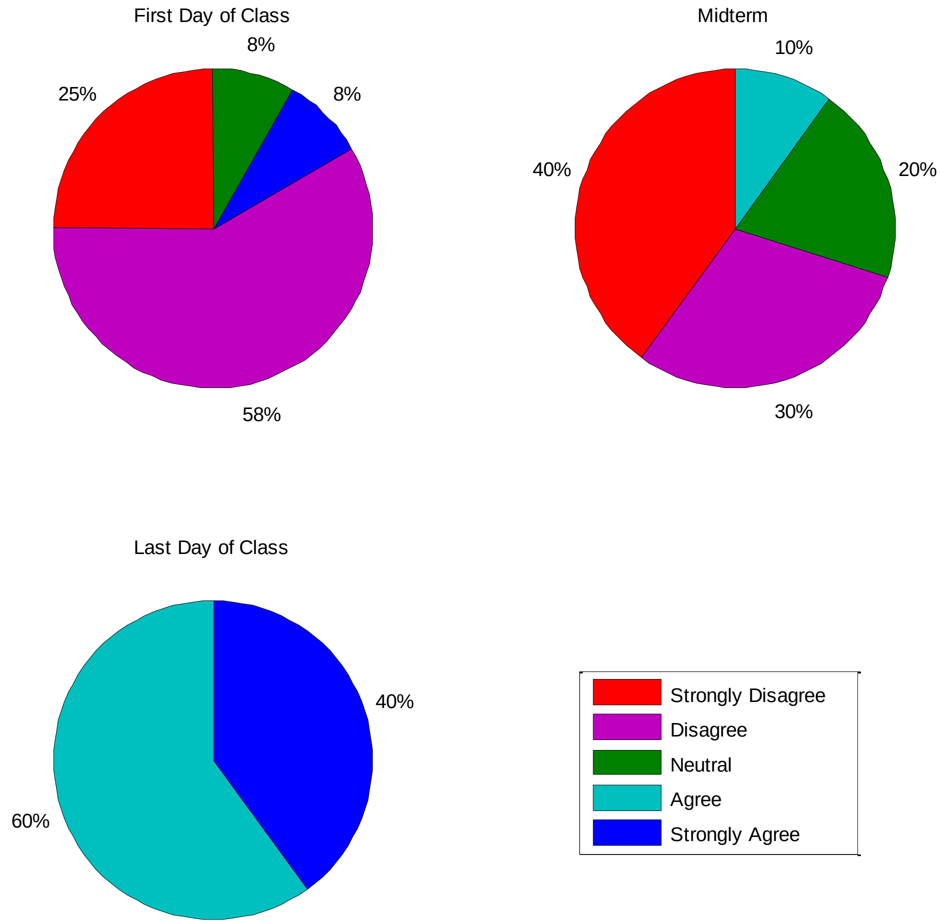

Figure 5: Survey Question "I have a strong understanding of the Political aspects concerning fuel cell technology"

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 assignments, there was a dramatic shift in student comprehension of broader impacts as seen in figure 5, 6, and 7.

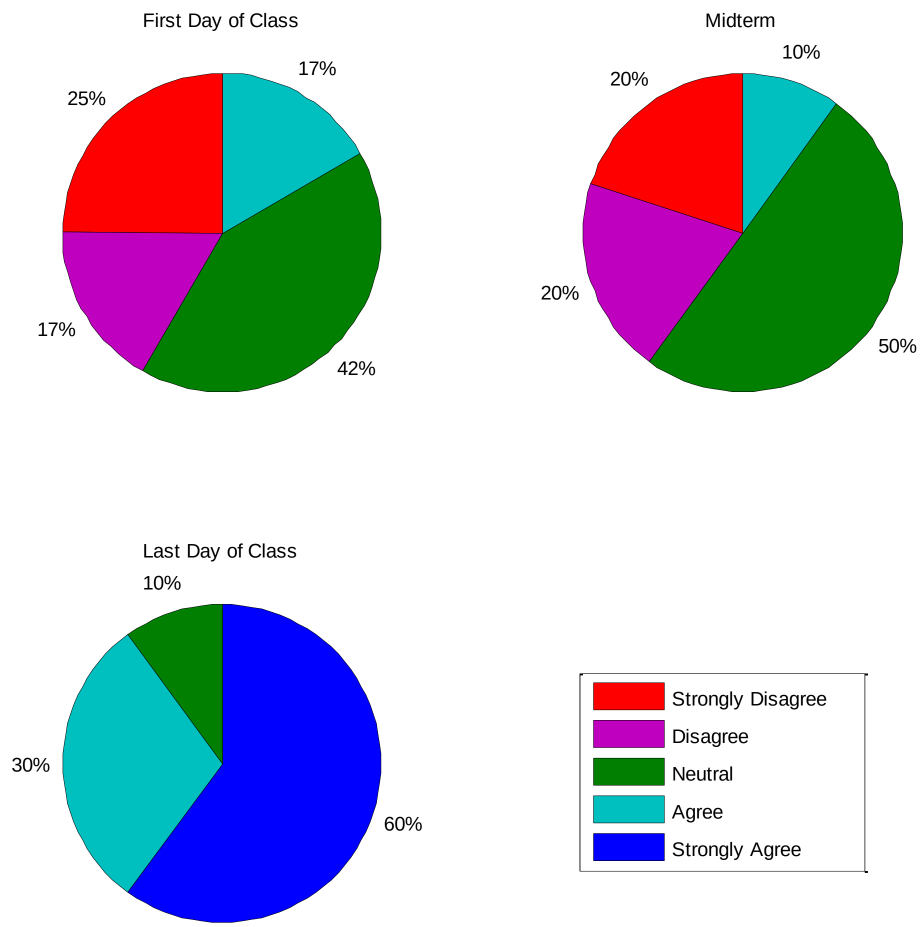

Figure 6: Survey Question "I have a strong understanding of the Economic aspects concerning fuel cell technology"

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. 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.

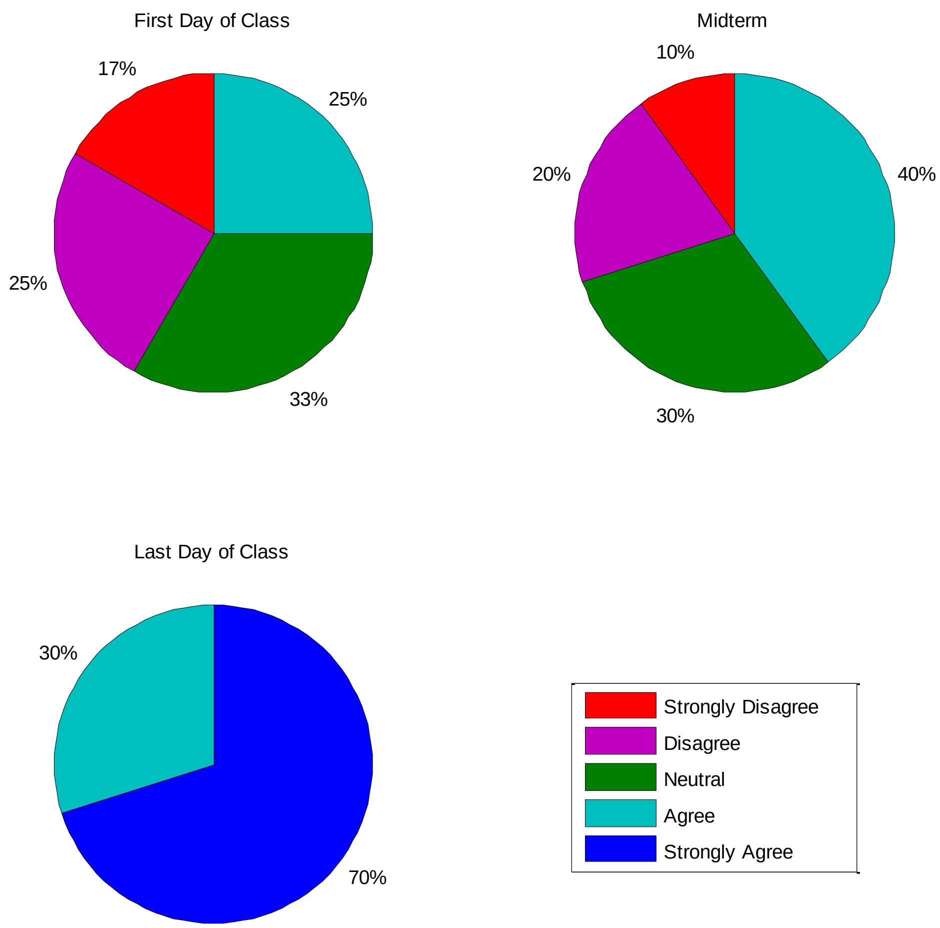

Figure 7: Survey Question "I have a strong understanding of the Social/Environmental aspects concerning fuel cell technology"

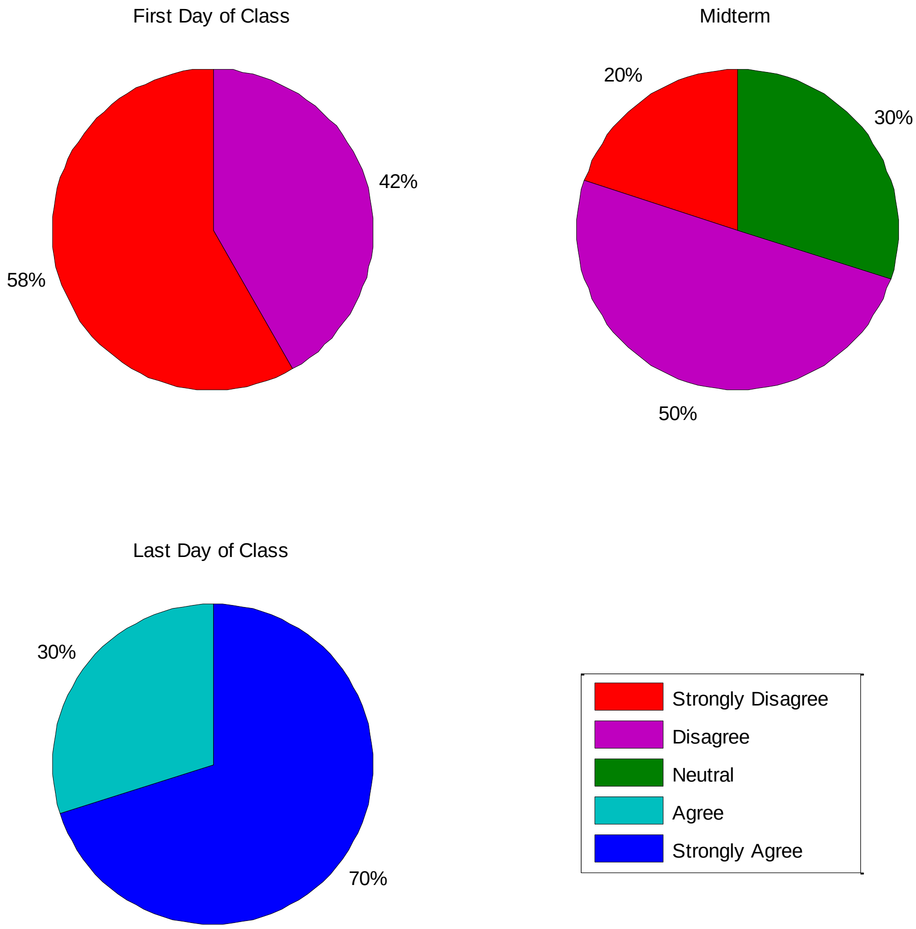

Figure 8: Survey Question "I have a strong understanding of the Balance of Plant aspects concerning fuel cell technology"

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 design and provide a real world application of fuel cells. As seen in figure 8, students' understanding of practical fuel cell system design increased significantly by the end of the course with all the students either agreeing or strongly agreeing that they understood aspects of fuel cell balance of plant. This observation of growth was further solidified during grading when an experienced fuel cell system engineer claimed that each group's design was just as good as or better than a majority of entry level fuel cell engineers.

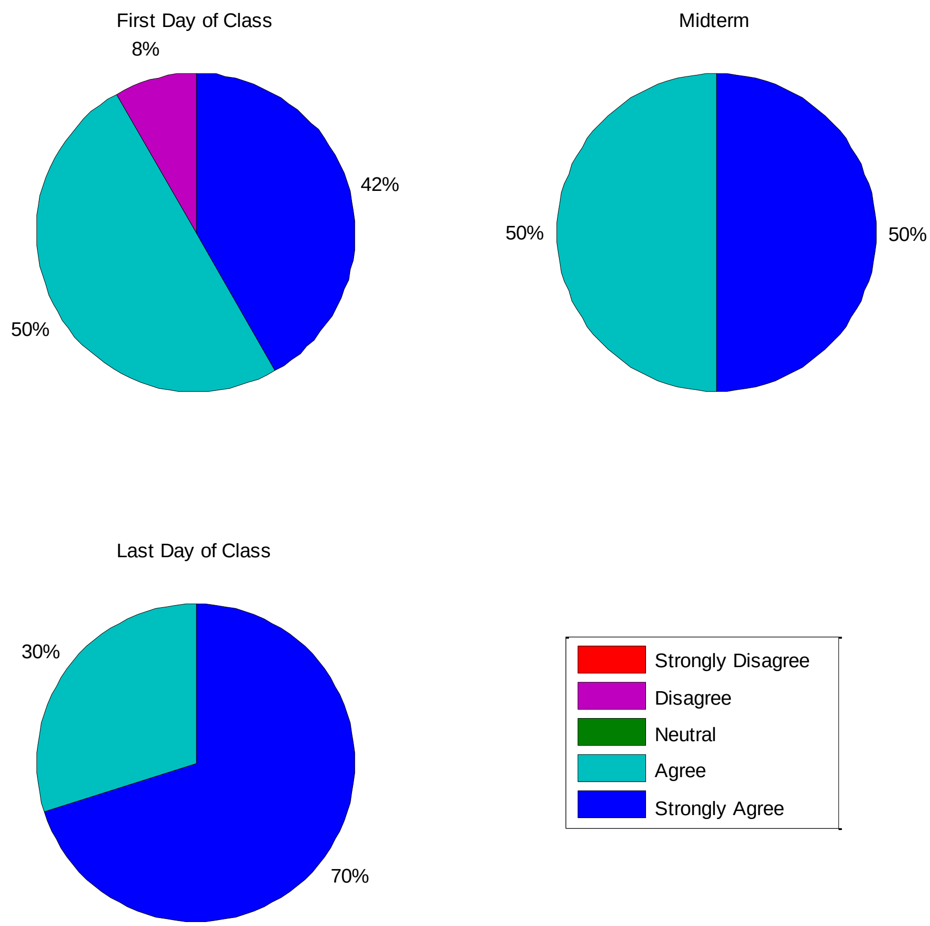

Figure 9: Survey Question "Hands-on laboratory experiments are powerful way to develop our teamwork skills and communication skills"

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.

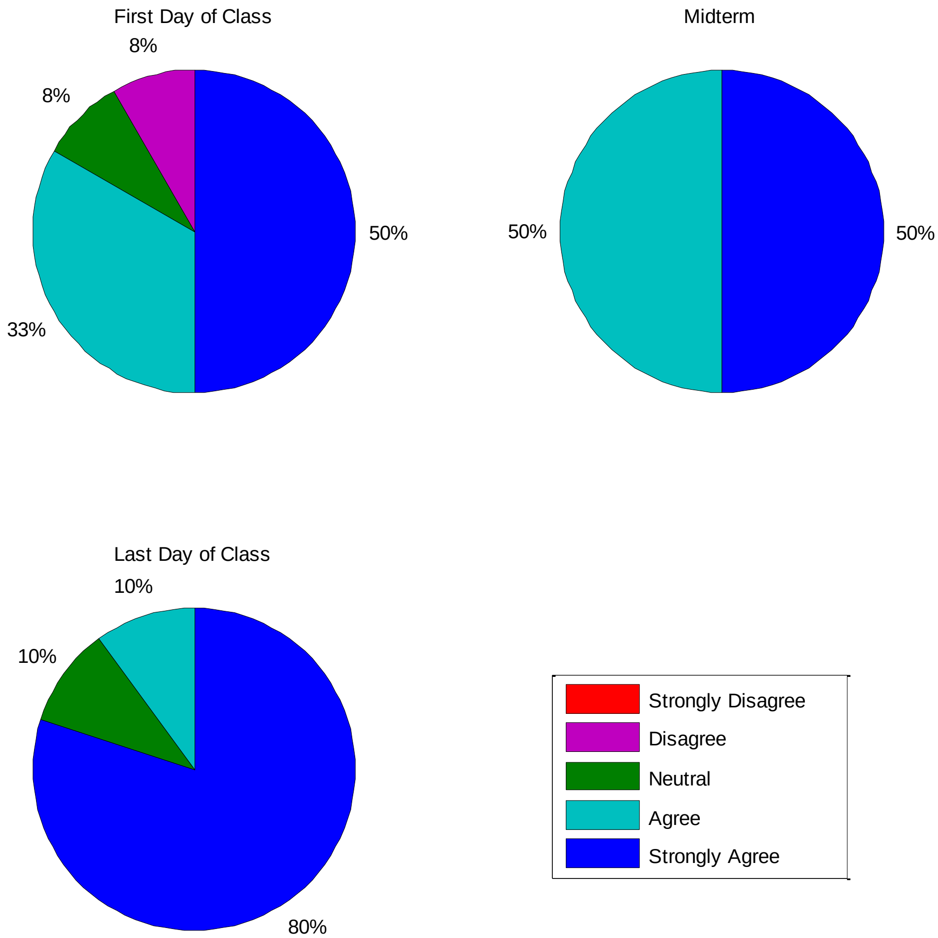

Figure 10: Survey Question "Hands-on laboratory experiments are a great way of reinforcing the concepts presented in lecture by building upon knowledge gained in lecture"

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. The reason for this change is not clear, but could be related to the students' indifference towards laboratory experiments or an insufficient link between the laboratory work and lecture. However, this gradual decline depicts the results from a small sample size and does go against the rest of the survey data, which showed a definite trend towards strongly agree.

Conclusion and Future Work

The Fuel Cell Science and Technology course contained a modified curriculum that encouraged T-Shaped professional skills through focus on fuel cell fundamentals and system design while also expanding on fuel cell technology's influence and role in different sectors of industry. The development of T-shaped professionals in this course was also closely linked with the development of energy systems engineers. The combination of a final fuel cell system design project that is multidisciplinary in nature, along with the development of team work skills and a broader perspective of fuel cell technology, encouraged this development. The surveys used to monitor students personal investment in the course was increasingly 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 by 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 its 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 teaching 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', signify that many students were eager to continue their investment in advance energy systems either in graduate school or industry.

This course also signifies the initial step into a transformative engineering education system. Starting with a single course it is possible to encourage innovative critical-thinking in eager engineering students. This 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 set an example for students leading the way for future innovative engineers. As more T-Shaped professionals emerge, it will be up to 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

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