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Exploring T-Shaped Professional Skill Development in Graduate Students in an Advanced Energy Systems Course

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Exploring T-Shaped Professional Skill Development in Graduate Students in an Advanced Energy Systems Course

Introduction

Graduate students come from a variety of backgrounds including various undergraduate disciplines, different nationalities, and different work experiences. Typically, graduate student can be categorized by their backgrounds. Students returning to graduate school from industry or those who have extensive academic research being labeled as experienced students while continuing students with little to no experienced can labeled non-experienced. This creates a major challenge for instructors who are required to find a way to educate and engage with students with various degrees of knowledge and skills. How does an instructor ensure that all students, both continuing and returning, learn the focused curriculum at a pace that is suitable for everyone? On top of this, graduate courses should aim to provide students with some means of furthering their professional development for future job prospects.

One common theme between, experienced and non-experienced students, is the common goal of advancing their education through a focused agenda. In a 2013 study, researchers found that most of the returning graduate students they interviewed were motivated by a utility value, or the students' interest in expanding their skill set and creating better opportunities[1]. Alternatively, one could argue that non-experienced students who continued straight from undergraduate already are motivated by a utility value, they want to further their education through a particular skill in hopes of improving their future job prospects. Therefore, establishing an accessible course curriculum that can engage both experienced and non-experienced students while expanding on a professional skill set would provide a common ground for both parties to work and grow together.

This paper draws attention to the development of the Fuel Cell Science and Technology course, which was initially offered exclusively to undergraduate students, then it was offered to graduate students for the first time this past spring. During the development of this course, key limitations were identified that restricted the education of future engineers, such as the finite time given to cover vastly expanding topics and the heavy focus towards textbook learning at the expense of hands on experience[2-5]. In order to fill the gap of students' broader knowledge, this course aimed to provide students with a balance between training in a single discipline and developing the capability of communicating and working with people across a variety of different fields[4,6-10]. This is also known as developing T-shaped professional skills and is depicted in Figure 1.

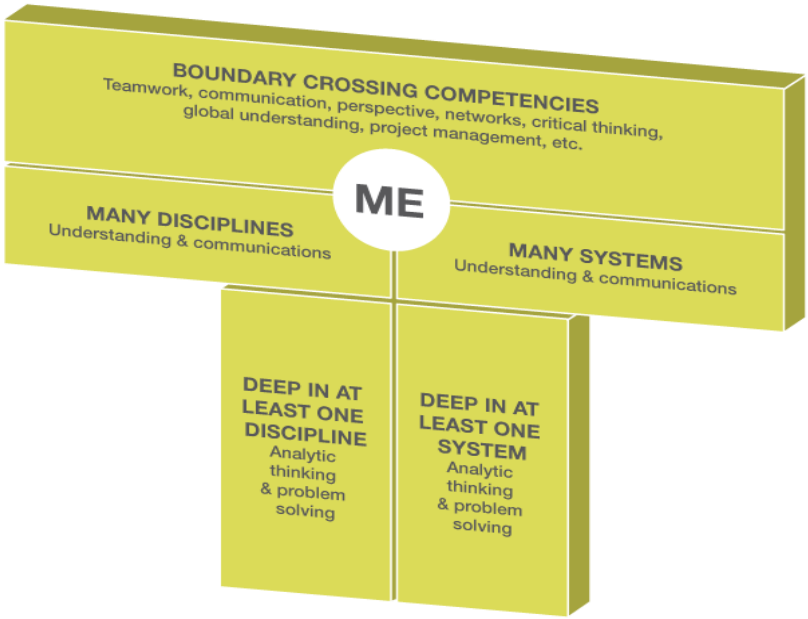

Figure 1: T-shaped professional diagram from T-Summit 2015[10]

In past semesters, this course has successfully pushed students to develop T-shaped professional skills with a deep understanding of fuel cell technology and the broader role in industrial society. Now, with the introduction of graduate students with different experience backgrounds, we can begin to T-shaped professional development at an extremely high level of education. This is achieved through a redesigned course curriculum that combines lecture material with hands on experience.

Course Program

Due to the limited laboratory availability, the course was limited to only 20 students. Almost immediately the course was filled within the first week. The course consisted of graduate students pursuing a degree in Mechanical and Aerospace Engineering with the exception of one student pursuing a degree in environmental engineering. The course demographic also contained mostly master students, with the exception of five students pursuing a PhD.

In accordance with the previous course structure, the course was divided into four portions: lecture, a seminar series, lab sections, and student's final project presentation. 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. In order to compensate for some student's lack of general chemistry principles, basic concepts were briefly introduced and appropriate examples were provided. 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 (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 Ratio Manipulation
	- System Integration

After the midterm exam, students participated in a seminar series that covered three class days. 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 discussed topics concerning fuel cell manufacturing processes and was led by a practiced research engineer. This served students the entry point into their laboratory sections where students would fabricate solid oxide fuel cells. The second seminar, titled Current Industry Practices of Fuel Cell Technology and led by an experienced ex-fuel cell engineer, discussed current industrial fuel cell systems and the major economic, political, and environmental policies influence on their application. The last seminar served as an introduction to the student's final project involving a brief overview of fuel cell system configurations and a step by step walk through of balance of plant design. At the end of the third seminar students were asked to divide themselves into teams of three. During the rest of the semester, each team would attend lab sections together and complete the final project at the end of the term.

The third section of the course was the lab section. Before beginning their assigned experiments, students were required to complete a safety quiz that demonstrated their understanding of laboratory restrictions and regulations. The laboratory experiments consisted of five sessions dealing with fabrication, testing, and characterization of fuel cells. All fabrication, configurations, and testing was conducted in the Combustion and Energy Research (COMER) laboratory, directed by Dr. Jeongmin Ahn[11]. This laboratory is equipped with a wide variety of instruments including two chemical fume hoods, impedance analyzer, and computerized Labview-based facilities for accurate partial pressure gas mixing and steady flow metering. 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. The performances of fuel cells were tested using an available power source meter also running under Labview.

The students' ability to fabricate and test fuel cells first hand was a way of reinforcing the course material learned in lecture. Each week groups were given individual 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. Teamwork can produce a superior outcome while giving students a sense of accomplishment, especially when the assignments are highly challenging[12]. Also allowing students to work together greatly improved communication capabilities which can increases an engineer's effectiveness significantly[10].

During the lab section, teams were given an outside reading assignment that was meant to encourage student discussion. Students were initially given a series of articles that provided a broader outlook on fuel cell technology. Each article consisted of key themes that highlighted various industrial sectors such as economics, political, social, and environmental. Out of all the articles, each individual student was expected to select a different article relating to the highlighted aspect of the week. After reading the article, teams were encouraged to have detailed discussions concerning what they had read, in order to create an open dialog of fuel cell technology. Each student was then expected to write a one page response, summarizing the article and linking it to the weekly assigned key theme. The one page response was evaluated based on the following criteria: 1) Students ability to accurately summarize the key topics of the article, 2) Students ability to relate fuel cell technology to that week's topic, 3) Students discussion on the implications of the articles discussion points, 4) Grammar and Spelling.

In doing so, the assignment would broaden student's perspective of fuel cell systems and its role in different areas. The assignment discussion portion would also encourage students to strengthen their communication with their teammates and give them a better understanding of different points of view. The last writing assignment consisted of a discussion of fabrication techniques, learned in the laboratory and chosen by the student, and its relation to wide scale manufacturing for commercial purposes.

For the last portion of the course, teams were given the task to design a portable solid oxide fuel cell (SOFC) system. In order to simulate a real world scenario, students were instructed to act as a fuel cell system design company, where they would be provided a set of constraints and materials used to create a design that would be later pitched to a board of "investors", comprising of two faculty members and two teaching assistants. Each component including operating conditions, selected materials, length of operation and detailed manufacturing layout were designated numerical values in which could be optimized through an iterative process. The design pitch also required a brief discussion of the broader impacts (political, economic, social, environmental, and manufacturing) of their design. While giving their pitch teams were evaluated based on the following criteria: 1) Number of achieved points, 2) Realistic design approach 3) Ability to address broader components 4) Ability to address questions 5) Presentation attire and skills.

In addition to monitoring student academic performance in the classroom, surveys were given at the beginning, middle, and end of the semester to provide individual student feedback. The survey was designed to anonymously establish student perception of the information presented in throughout the course and observe their progress in exploring broader topics. The survey asked students their thoughts of understanding broader impacts, hands-on research experience, and if the overall course generated a continuation in engineering fields. The answers ranged from strongly disagree to indifferent to strongly agree on a scale of one to five.

Results and Discussion

At the conclusion of the course, the survey data was compiled for further analysis to see the courses' effectiveness of developing T-shaped professional skills for graduate students. The survey's first question aimed to established student feedback concerning their overall understanding of the fuel cell discipline (i.e. the vertical component that begins to form a T-shape professional). In past years, when this survey was distributed to undergraduate students, most students showed a defined progression of students disagreeing with understanding to the course material at the beginning of the course to almost a complete strong agreement of understanding at the end of the semester[13].

In this case the majority of students agreed with understanding the material, but there were some students that felt indifferent or disagreed, reserving some of the judgements about what they had learned overall. This was complemented by student's overall performance with a large majority of students receiving high marks with a small number of students receiving a grade of B or lower. This comparison between student overall performance and student's perception of understanding provides some interesting insight as to how students judge themselves and in this case accurately access their own performance. When looking at over aspects concerning these parameters, similar trends were seen.

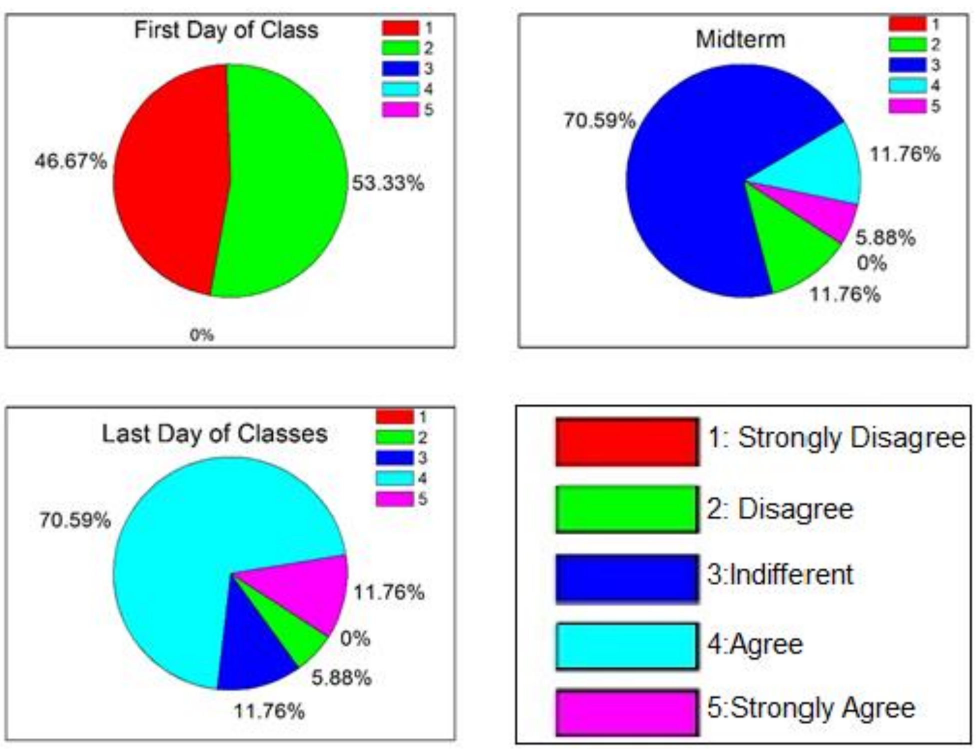

Figure 2: Survey Question "I know a lot about Fuel Cell Science and Technology"

The next series of survey questions comprised of questions focusing on the broader aspects of fuel cell technology and application. Similar to the first question, a small minority of students held some reservations as to whether or not they completely understood political and environmental/social aspects concerning fuel cell technology. Further seen in Figure 3 and 4, over the entire semester a majority of students felt that they gained some knowledge pertaining to certain aspects, but there were one or two students that felt indifferent or disagreed.

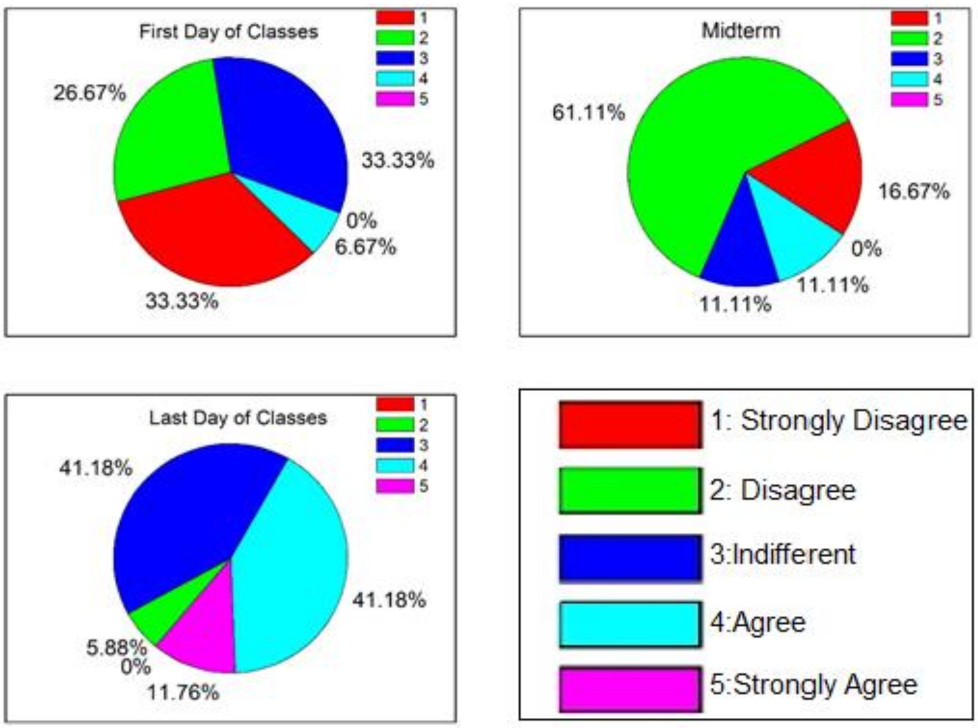

Figure 3: Survey Question "I have a strong understanding of the Political aspects concerning fuel cell technology"

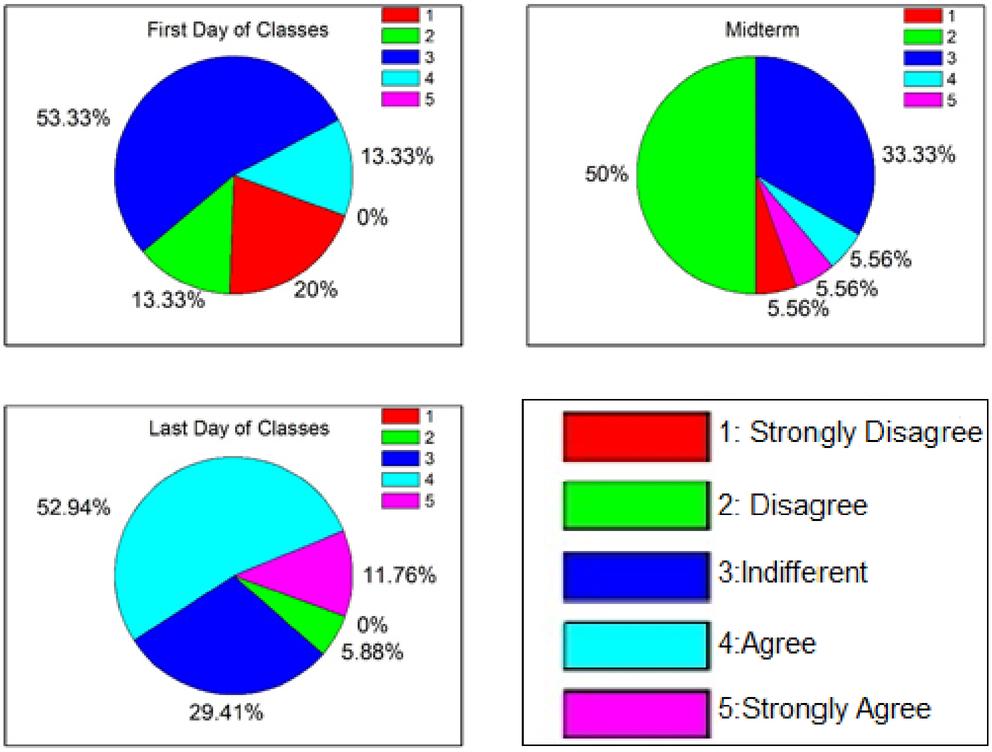

Figure 4: Survey Question "I have a strong understanding of the Social/Environmental aspects concerning fuel cell technology"

When examining teams final presentation a similar trend was identified. One of the criteria's used to evaluate the team's final presentation was their ability to link their design to broader ideas. Although student showed strength in some areas, some teams lacked the ability to construct a broader impact their design had. For example some teams discussed the restriction on harmful pollutants, but failed to clearly identify how their design would effectively reduce said pollutants. Although some students showed a lack of understanding in certain broader aspects there was a much stronger response for student response concerning economic aspects.

As seen in Figure 5, student believed they gained a stronger understanding of economic aspects pertaining to fuel cell technology. In the beginning of the semester most students believed they had no context to economic aspects, with the exception of one student. As the semester progressed, more students began to gain a stronger understanding until the end of the semester where students either strongly agreed, agreed, or were indifferent with learning how economic aspect concerning fuel cell technology.

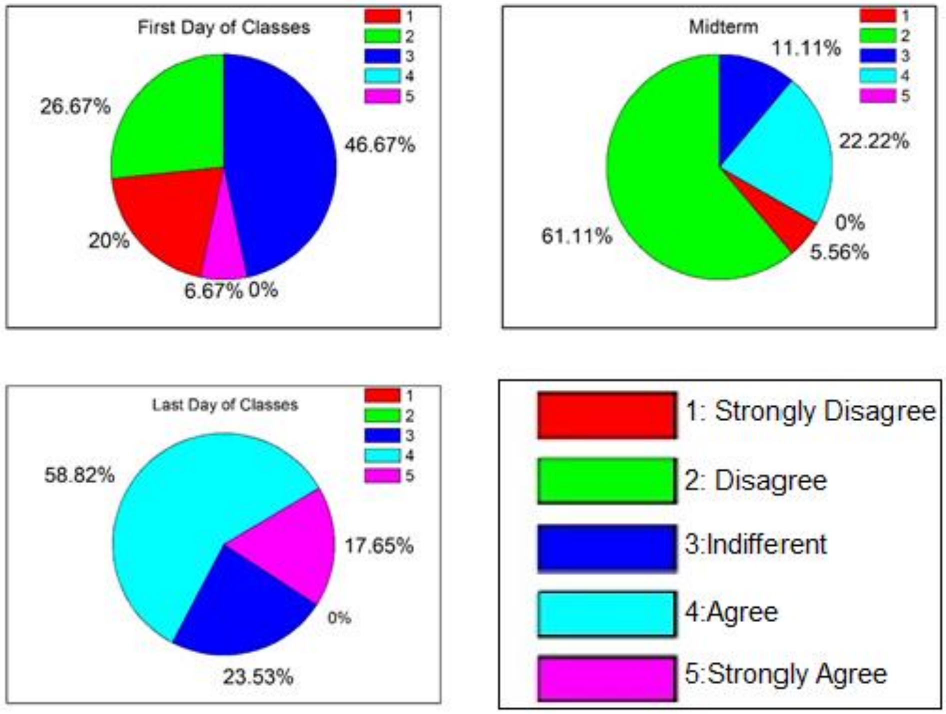

Figure 5: Survey Question "I have a strong understanding of the Economic aspects concerning fuel cell technology"

When compared to the other broader aspects discussed, it is clear to see why there was much better student understanding of economic aspects. The final project, given to students in the middle of the semester, placed the team's design in the context of cost of manufacturing, time, and resources. As stated before, part of the student design criteria was based off a point system that evaluated the cost of system and manufacturing components. In this context, students were required to think more actively about the decisions that they made based on value of resources and whether or not that would aid or diminish the total amount of points earned for their design. This type of active think was further seen in student discussion in the lab section, with many students taking an interest in fuel cell materials and their market availability as well as the overall manufacturing costs of fuel cell processes.

Another key component of the final project that simulated a real world application design was the idea of balance of plant, or how other components included in the design were supported by the fuel cell power source. In order to achieve the optimum design, students were given a introductory lecture on how to calculate the balance of plant. When looking at student perception of understanding balance of plant, as seen in figure 6, the value increased significantly by the end of the course with most of the students either agreeing or strongly agreeing that they understood balance of plant. However, one student strongly disagreed that they had any understanding of balance of plant even at the end of the semester. Regardless of the individual opinion, the graded final projects indicated that each team's designs were just as good if not better than a majority of entry level fuel cell engineer.

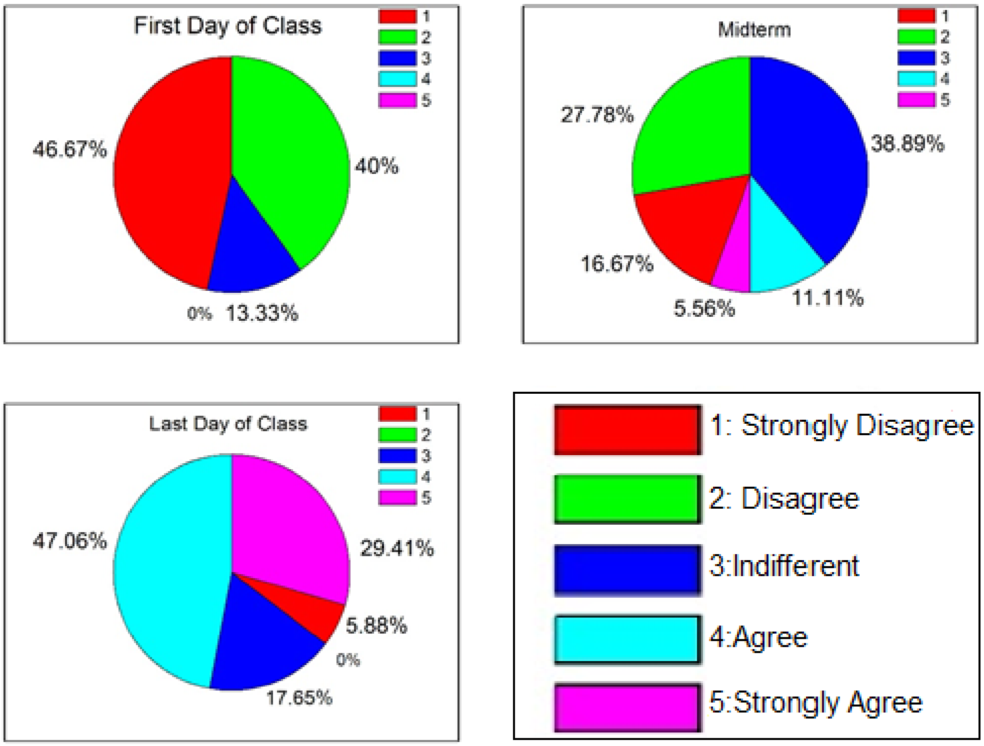

Figure 6: Survey Question "I have a strong understanding of the Balance of Plant aspects concerning fuel cell technology"

This raises a serious question as to why some students perceived to have a strong understanding of certain aspects of the course, even though in past semesters, when this course was offered to undergraduate students, there was very little reservation. One conclusion could be drawn when examining the profile of the graduate student experience. When asked if they had any industrial experience with full time positions, internships, or external collaborative research projects, 40% had said yes and provided examples of their past experience. It could then be inferred that since a large number of students had worked on industrial projects, some students could have more reservations that they had truly gained a strong understanding of the certain aspects in class. A student who worked on a government funded project that tied into some political agendas could believe that the lessons learned in class were not broad enough to thoroughly understand a particular aspect. If a student had no prior experience, they could believe that the material provided was sufficient enough to have a broader understanding.

Despite reserved student perceptions, many of the student's final project were insight providing creative and innovative way for the dealing with the final project. For instance, one team approached the portable fuel cell design with writing a computer program that incorporated all of the project constraints, then proceeded to run through a continuous iterative process until the optimal point was found. Another team, which focused much of their design on the fuel cell manufacturing process, incorporated an innovative fabrication technique which significantly reduced production cost. Consequently, most students scored fairly high on their final presentations with most students demonstrating some gained understanding in fuel cell discipline and its broader impacts.

Conclusion and Future Work

This paper presents the Fuel Cell Science and Technology course, which for the first time was offered to graduate students. The course was designed to encourage T-shaped professional skills through the focus of fuel cell fundamental discipline while also expanding on fuel cell technology's influence and role in different sectors of industry. The course was broken in to four sections including a standard lecture, a four day lecture series, hands on laboratory experiments, and a practical final project. During the semester, surveys were given to students in order to monitor their progression of knowledge through the course. Despite past positive feedback from past courses, there were a small minority of graduate students who felt indifferent or disagreed with full understanding of some elements highlighted throughout the course. One possible reason was due to the experience level of some experienced graduate students, who might have perceived or not fully understood certain highlighted aspect of the courses compared to past encounters dealing with those aspects.

Although the surveys indicated a small minority of students who perceived to not understand certain aspects in the course, there was no indication of it in the instructors' evaluation of the students' final project. In fact, most of the projects presented showed innovative ways for finding the optimal points for the balance of plant design and provided a unique perspective as to how fuel cell technology plays a role in political, economic, and social/environmental aspects in industrial application. Due to its limited time, the course was not able to cover all topics concerning the application and technology in the fuel cell field, but was able to start a discussion among students from different backgrounds. The instructor observed an interesting relationship between experienced and non-experienced students during the course. It appeared that those with industrial experience would contribute ideas that would widen the perspective of some non-experienced students, not only improving their knowledge, but shaping their professional skills as well.

Since the majority of students showed a progression of gaining a thorough understanding of the fuel cell discipline and the broader role it plays across various fields, it can be concluded that the course succeeded in encouraging T-shaped professionals in students. This course can then be seen as an example for others to begin to integrate some of these described techniques into undergraduate and graduate classrooms. This would hopefully create a new generation of engineers that hold different prospective on particular fields, ultimately improving innovative thought and design.

Acknowledgments

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