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Revitalizing Engineering Education through Practical Applications of Advanced Energy Systems

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Ryan is a graduate student from Syracuse University with a focus in combustion and energy research. His work mainly focuses on fabrication and characterization of ceramic hollow fibres used in combustion processes that can reduce pollutant emissions. Ryan is also involved in several educational outreach projects concerning his research. Not only does he assist in the development of advanced energy courses for undergraduate and graduate students, but also has been involved in STEM Education Initiative programs at the high school level.

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Prof. Jeongmin Ahn is an Assistant Professor in the Department of Mechanical and Aerospace Engineering at Syracuse University (SU). Prof. Ahn received a B.S. degree in Mechanical Engineering from the Rensselaer Polytechnic Institute, a M.S. degree in Aerospace Engineering from the University of Michigan, Ann Arbor, and a Ph.D. degree in Aerospace Engineering from the University of Southern California. Prof. Ahn has extensive research experience in combustion, power generation, propulsion and thermal management. He performed an experimental investigation of catalytic and non-catalytic combustion in heat recirculating combustors, solid-oxide fuel cells, micro heat engines, thermoacoustic engines, and thermal transpiration based propulsion and power generation. He has worked on a DARPA project to develop an integrated microscale power generator based on a solid-oxide fuel cell employing hydrocarbon fuels. Currently, his research is conducted in the Combustion and Energy Research Laboratory (COMER) at SU. Prof. Ahn has published over 20 papers in peer-reviewed journals (including Nature and other high impact journals) and a book, and made over 100 technical presentations (including over 20 invited seminars in Korea, Japan, China, Germany, and United States). He is an Associate Fellow of the American Institute of Aeronautics and astronautics (AIAA) and served as a Board of the Combustion Institute. He is a recipient of the Society of Automotive Engineering (SAE) Ralph R. Teetor Educational Award, LCS Faculty Excellence Award, CEA Reid Miller Excellence Award and WSU MME Excellence in Teaching Award. He has also been named AIAA's Spotlight Member of the Month and awarded the WSU Faculty Excellence Recognition Program.

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Introduction

The low percentages of students being retained in engineering majors have been well documented [1]. Without increasing the numbers in this subset, it is difficult to impact the numbers of new graduates entering the workforce and pursuing higher degrees. The problem with the general image of engineering that is known to contribute to low enrollments is the lack of understanding of how engineering can be used to improve society.

One way to this image is to engage students in hands-on experiments. The students' interest in science and engineering can be increased if they are exposed to more hands-on research experiences rather than what is traditionally offered in undergraduate curricula. Those personal student experiences can encourage students to continue in their STEM major.

Recent engineering students are known to express great interest in activities focusing on energy and a cleaner environment [2]. Exposing students to the exciting developing field of energy and the environment while participating in hands-on experiments in the classroom can stimulate the scientific curiosity and imagination of young people. This increases the likelihood that they will continue their engineering major. To satisfy the students need, a new elective course in Fuel Cell Science and Technology with hands-on laboratory experiments was developed by Dr. Jeongmin Ahn and the Mechanical and Aerospace Engineering Department at Syracuse University.

In order to retain students in engineering, four fundamental principles were established that acted as the foundation of the educational approach for the course:

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.

These listed principles presented a clear course objective of broadening participation and improving student retention in engineering education through an integrated program of scientific research and education.

Course Program

The course was designed to enable students to understand and evaluate fuel cell systems and technologies and their environmental consequences. Many of the fifteen enrolled students varied in disciplines outside of Mechanical Engineering including Physics, Aerospace and Chemical Engineering. In order to appeal to all disciplines, course topics were organized into basic concepts that cumulated over each class.

The course was divided into two portions: lecture and lab experiments. The lectures met twice a week in a classroom setting and discussed fuel cell fundamental. The topics included fuel cell thermodynamics, electrode kinetics, performance and efficiency, transport process, types of fuel cells, fueling issues, and fuel cell systems and applications seen in the table below. During most lectures the technical challenges and direction of fuel cell in future applications were also discussed. After seven weeks, students were given a midterm exam. The exam incorporated basic analysis of electrochemical and thermodynamic principles while also asking students to discuss the characterization and system integration of the different types of fuel cells.

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 Ration Manipulation
	- System Integration

At the conclusion of the lectures section, all fifteen students were given a unanimous midterm course evaluation. The evaluation asked students their personal thoughts of the hands-on research experience and the motivational impact of the lecture material. The survey also focused on the lecture section of the course, providing feedback as to 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. Students would be given a similar survey after the completion of the overall course.

Shifting into the second half of the semester, students began preparing for laboratory experiments by performing necessary safety evaluations and exploring various details of fuel cell fabrication and testing through reading assignments from current literature. The laboratory experiments 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.

To ensure the personal satisfaction and appreciation of the laboratory experiments, students were divided into groups of three or four and placed on a rotation schedule broken into two lab sections that met once a week. Permitting only two groups per session allowed students to take full advantage of the laboratory environment. During each section both groups were given individual experiments to complete in the given class time. All experiments specified a technique that 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 [4]. Also allowing students to work together greatly improved communication capabilities which can increases an engineer's effectiveness significantly [5].

All fabrication, configurations, and testing was conducted in the Combustion and Energy Research (COMER) laboratory, directed by Dr. Jeongmin Ahn [3]. 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 soli 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.

Each group was able to utilize all of the COMER laboratories' equipment through the assigned experiments. In order to fully understand how to operate the fabrication machines, groups were paired with a teaching assistant who had extensive experience with the specific machine. For each experiment, the teaching assistant would discuss with groups the broad idea of how certain aspects of the experiment related to fuel cell sciences, then go on to show the groups how to perform the experiment.

Figure 1: Students learning fabrication techniques in laboratory experiments.

All experiments followed a general process of the fabrication, classification and experimentation of fuel cell systems. Students were taught how to select the specific powders that were used to fabricate a fuel cell. Students then examined various manufacturing techniques, such as tape casting, extrusion, and dry pressing that were used to produce planar and tubular cells. Using student produced cells, groups were shown how to characterize and test cells with a power source meter. The last experiment consisted of students experimenting with housing mechanisms that incorporate fuel cells to generate power. After completing the experimental portion of the course, groups were asked to create a 30-minute presentation which demonstrated what they learned from the laboratory experiments and how those experiences related to the lecture material. Groups were also asked to incorporate their own views on how fuel cell technology could be used in real world applications.

Results and Discussion

The final presentation gave students the opportunity to show their understanding of the overall course material. As a result, all presentations proved that students gained a stronger appreciation for all course topics. Each presentation consisted of groups discussing their views on the advantages and disadvantages of the fabrication process learned in each laboratory experiment and how fabrication processes can be determined based on application. Several students also displayed qualitative insight into material selection processes that determined the composition of fuel cell categories. Most importantly, students also presented specific ideas as to how fuel cell technology could be implemented in real world industry including fuel cell integration in advance circuitry, automotive systems or other hydrocarbon burning units.

After completing all presentations, all fifteen students were asked to complete another unanimous feedback survey with similar questions to the midterm survey. These questions focused on the overall course, providing feedback as to whether or not interest was increased, if the lab sessions were effective, and if the overall course generated a continuation in engineering fields. Similar to the midterm survey, the answers ranged from strongly disagree to neutral to strongly agree on a scale of one to five.

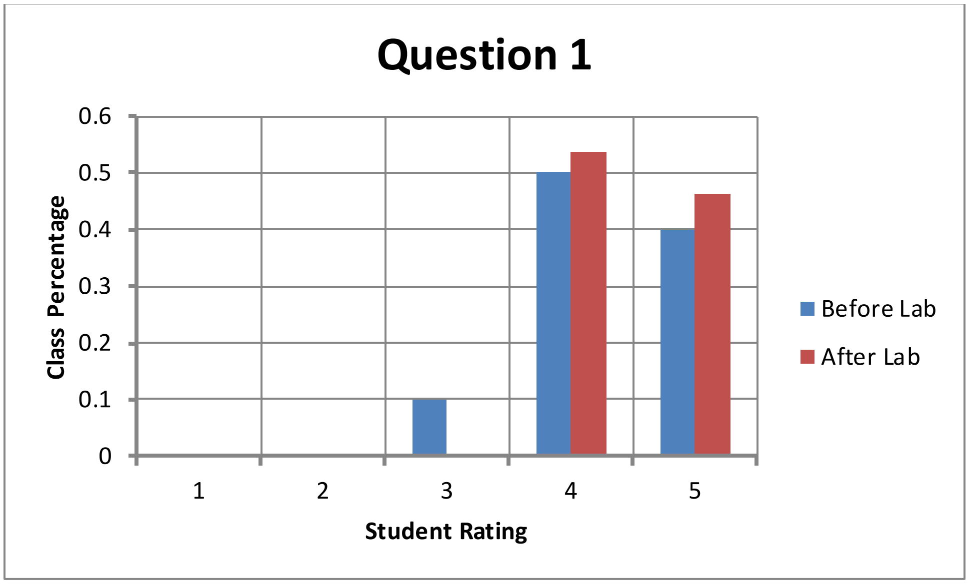

Figure 2: "My interest in science and engineering was increased"

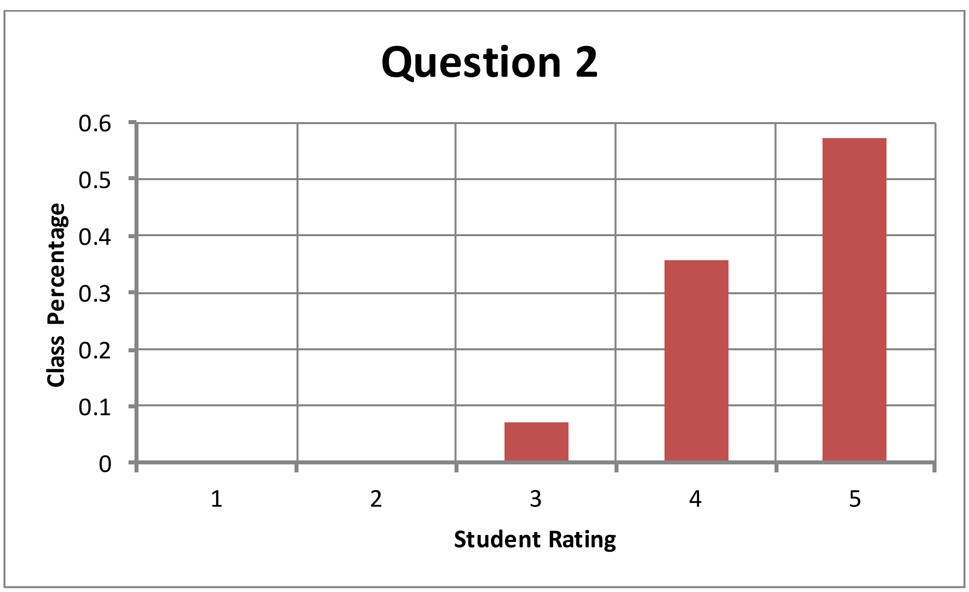

Figure 3: "Lab sessions greatly reinforce the concepts presented in lecture by building upon the knowledge gained from the classroom"

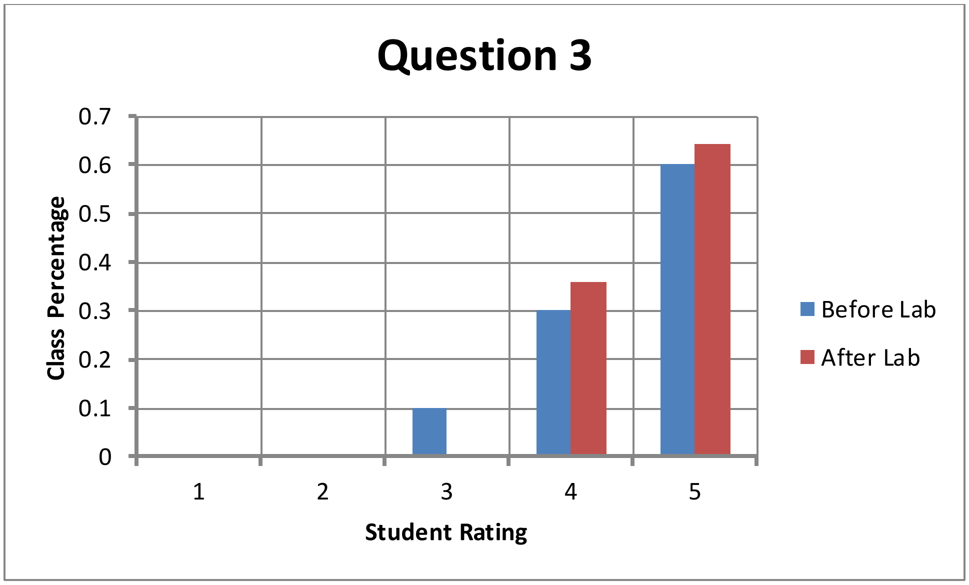

Figure 4: "This class stimulates my scientific curiosity and imagination and thus increases the likelihood that I will continue my career in the engineering fields (graduate school, engineering industry)"

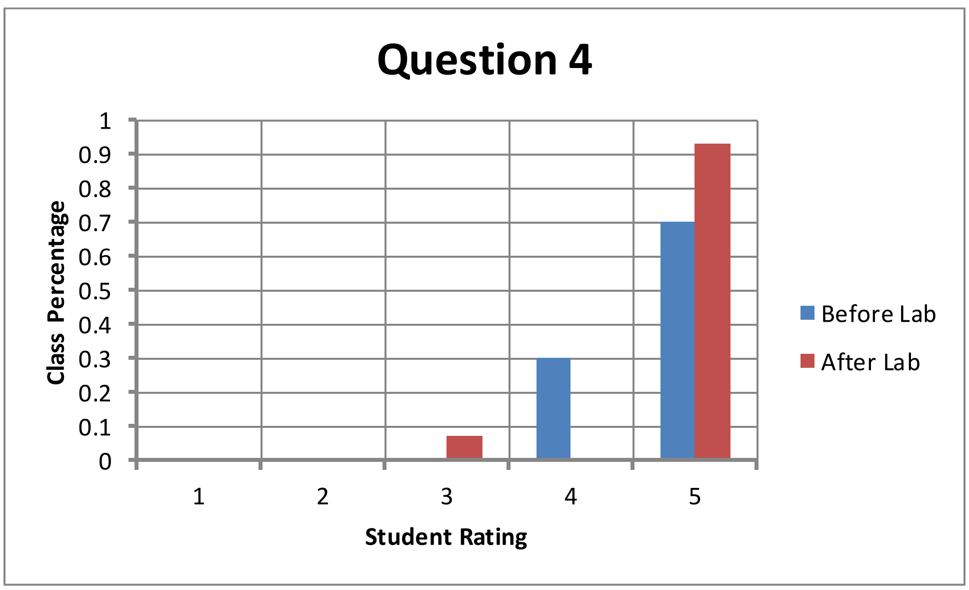

Figure 5: "I would like to suggest that our curriculum should have more hands-on sessions"

The figures above show a comparison between the survey results after the lecture section (midterm survey), then after the laboratory section (final survey). It can be seen that there was no student in the class who provided any "strongly disagree" or "disagree" feedbacks for all the questions in both midterm and final surveys. It can also be seen that the hands on experience gained in the laboratory section of the course had a significant impact on students understanding and appreciation of the material.

Student interest in science and engineering significantly increased after the laboratory section when compared to just after the lecture seen in figure 2. Also, figure 3 showed that the majority of the students strongly agreed that lab sessions greatly reinforced and expanded on the concepts learned in the lecture section. Furthermore, from the results seen in figure 4 it was concluded that the lab sessions improved student's scientific curiosity from 90 to 100% of the students who also had interest in continuing their careers in the engineering field. Lastly, the final survey also presented, from figure 5, the notion that the majority of students in this course had extremely high demands for hands-on lab sessions in other courses which could reinforce the concepts in those lectures.

Conclusion and Future Work

The Fuel Cell Science and Technology course provided students with hands on laboratory experiments that could build upon the knowledge gained inside a classroom setting. The majority of the students responded positively to the curriculum and showed a strong retention of the course material through the synergistically integrated program. This combined teaching method not only consisted of fundamental concepts being reinforced through laboratory experiments, but also developed a personal gain of abstruse knowledge in each student. Based on their responses, more students will be able to enroll in the course in upcoming semesters. The future course will still up hold the fundamental teaching principles previously dictated while also accommodating the student demand for a more integrated laboratory experience. In doing so, additional students can be exposed to a professional research environment which will instill a stronger confidence in students as they pursue their goals in an engineering career.

Acknowledgments

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