Fuel Cells and Discovery-Oriented Teaching

Camille George
Programs in Engineering & Technology Management
University of St. Thomas, St. Paul Minnesota

Abstract
Fuel cells and the hydrogen economy are mentioned in every media outlet. However, the average graduating mechanical engineer does not know any more about fuel cells than an interested layman. Are our future engineers equipped with the inquiry-based skills needed to adapt to rapidly changing technologies? A fuel cell engineering class has been introduced at the University of St. Thomas (UST) where students were challenged to acquire new information, to collect data, analyze it and express an educated opinion. The pedagogy of the class was discovery-oriented. The approach was in stark opposition to the established lecture, textbook, homework and exam tradition. Students initiated their own learning, an experience that cannot be overemphasized for future problem solvers. Assignments included student-led lectures and discussions, a formal laboratory notebook, and a final thought experiment written in the form of a proposal. Students' experimental proposals, lecture topics, and lab experiments will be presented in this paper.

Introduction

Engineering education must create *innovators.* How does one gather new information, assemble it in some meaningful way, examine it, criticize it and comprehend it? The goal of the class was to lead the students through the different phases of thinking skills. These skills are more often practiced in liberal arts classes such as sociology or journalism. Engineering classes are usually taught as a fixed body of knowledge of which the professor is an expert. Chapter readings and homework are assigned, exams have right and wrong answers, and solutions are known by the professor. In reality, few industrial problems are like text-book end-of-chapter problems. Real life situations are full of incomplete and unknown data, setbacks and puzzles. Engineers are supposed to design and build <u>new</u> products, devices or processes.

Many engineers of today and tomorrow will work at the cutting edge of their profession. In today's world, they must be equipped to go from project to project, often having to engage in a large amount of self-study to 'get up to speed' on a certain problem. Unfortunately, on the undergraduate level few students are given the opportunity to learn in an open learning environment where they must take responsibility of synthesizing large amounts of material from disparate sources.

One of the most important public issues of our time is the cost, production, and impact of our energy usage. Oil, gas, nuclear, and alternative energy have consequences for our natural world. To engage effectively in the discussion, one must have grounding in critical scientific and mathematical thinking. Today's students will be called upon to use established knowledge mixed with a spark of creative insight to solve our global energy needs. Engineers have the power to make a difference. Because of their viability as environmentally friendly 'engines', fuel cells and the hydrogen economy may provide a link between alternative energy (wind, solar) and energy-on-demand. By examining fuel cells, students become *eyewitnesses to an emerging technology.* By examining an emerging technology, students are forced to use higher order thinking skills. Fuel cell technology is changing at an enormous speed- no one has all the answers, and there are numerous equipment and economic challenges for tomorrows' engineers before this technology takes hold.

Course Description and Objectives

The main objective of the class was to develop discovery skills in the context of learning about a new technology. The stated learning objectives of the course are detailed in Table I. *Fuel Cell Engineering* was offered as a topics class in the spring of 2003. The description of the course according to the UST catalog offering is "A discovery-oriented pedagogy focused on fuel cell technology. Fuel cells types, their chemistry, physics, design, safety, cost and operation are examined. Considerable time will be spent on hydrogen generation, storage & distribution. ENGR 297 fulfills four credits of engineering electives."[1] Fourteen undergraduate students at the junior and senior levels and two-adult learners from the community participated in the course. The course met three times a week with a lecture time of 65 minutes, over 14 weeks. The class was featured on the Minnesota journal, a weekly local environmental program. A video clip of the program and student interviews can be viewed at www.stthomas.edu/engineering/News/FuelCell/Default.htm .

Table I. Learning Objectives for Fuel Cell Engineering

KNOWLEDGE AND INSIGHT

1. To learn the current state of fuel cell technology.
2. To understand experiments and data acquisition.
3. To practice the process of science.
4. To examine the viewpoints of business and politics in regards to a new technology and societal change.

SKILLS INVOLVING TOOLS

5. To be able to solve problems and analyze processes with a rational methodology.

CRITICAL THINKING AND CREATIVITY

6. To challenge the students to think about contemporary issues.
7. To develop a critical appreciation of the depth of this subject matter.

ARTICULATION AND COLLABORATION

8. To practice engineering communication in both the written and oral format.
9. To develop team skills.

Structure and Course Content

Class time was split equally between lectures, guest speakers from industry, and hands-on laboratories. Table II presents a summary of the major topics covered in the course. The course content was roughly 80% physical science and engineering, and 20% social and political science.

Table II. Content Covered in Fuel Cell Engineering

Topics
February –'*Fuel*'
Intro & overview of fuel cells.
Fuels: energy density, processing, availability, cost & safety.
Hydrogen reformation.
Hydrogen generation, distribution, storage.
Methanol.
Air handling & oxygen supply.
Fuel cell poisoning.
March – '*Cell*'
Operation of a single cell.
Basics of energy conversion, electrochemistry, electrodes, potential gradients, electrolytes & catalysts.
Fuel cell thermodynamics & efficiency.
Kinetics & transport phenomena of electrochemical systems.
Types of fuel cells: PEM, SOFC, direct methanol, alkaline & other high temperature cells.
Materials of components.
Membrane materials, hydration & performance.
Fuel cell stacks, power density, loading response, over potentials, losses & limitations.
April – '*Systems*'
Stack configurations; geometries, flow fields, gaskets, cooling plates.
System integration & design.
Manufacturing for high volume.
Power conditioning, power diodes, control systems.
Automotive applications & issues.
Micro fuel cells & portable power.
Distributed & stationary power.
Field-testing & status of development.
May – '*Politics & Business*'
Economics & infrastructure investment for fuel cell development.
Status of codes & standards.
Public policy, congressional bills, legislation & societal change.

Implementation

The professors' expectations were clearly stated and the measured learning outcomes are listed in Table III.

Table III. Learning Outcomes for Fuel Cell Engineering

A. **Student led lecture and discussion:** Addresses the issues arising in new technologies; helps gain knowledge of where to get information, develops the ability to write effectively; and to give an oral presentation.
B. **Design of a Thought Experiment:** Demonstrates the ability to apply a limited knowledge base to an open ended problem; develops the capability of analyzing a question and writing a rational plan to answer the question; develops the ability to write effectively.
C. **Laboratory Notebooks**: Demonstrates that the student understands experimental data gathering and is able to analyze a question and work with a partner.
D. **Solving fuel cell problems:** Requires interdisciplinary knowledge and educated guesswork.

Students selected a topic to research the first week of class. They were expected to become a mini-expert on their topic and give a 30 minute lecture with hand-outs and notes. Several background lectures were given by the author using lecture notes obtained from the University of Washington.[2] A general review of fuel cell technology and basic engineering principles were found in the required outside reading.[3-5] Students were encouraged to use liberal arts methods such as media reading, discussion, and structured controversy to connect the technical world to the everyday world. An effort was made to promote student understanding of how engineering involves people, globally and individually. Students were expected to find out what is known, unknown and disputed about their topic. Every student graded their peers on a scale from 1-4, on technical content, presentation skills, and topic synthesis.

As a final project, students were asked to design a thought experiment to address a question that they were curious about. The thinking skills required for this project were complex; students needed to comprehend, synthesize, and evaluate the issues. The experimental plan was submitted in the form of a proposal complete with a bill of materials and budget. An expert on design of experiments was invited to the class to explain some key concepts of design of experiments and to act as a consultant.[6] The proposals were graded on creativity, scientific reasoning, writing mechanics and professionalism. A sample 'request for proposals', from our state energy fund, was used as a guide for the students to follow. (i.e. abstract, introduction, experimental design, budget, page requirements, font, word count etc.) Some of the student proposals are listed in Table IV.

Table IV. Examples of Proposals for Experiments Developed by the Students

1. Comparison of Off-Design Conditions of Solid Oxide Fuel Cells with Proton Exchange Membrane Fuel Cells
2. An Experimental Investigation of PEM Fuel Cell Water Management and the Effects of Ambient Air Humidity on PEM Fuel Cell Performance
3. An Experiment to Compare Fuel Cells to Batteries
4. An Experiment to Determine the Power Range of Glucose Fuel Cells
5. Experimental Design to Investigate the Effects of Hydrogen Embrittlement
6. An Experimental Set-Up to Power a Remote Freezer with a Dual-Use PEM Eletrolyzer/Fuel Cell and Wind Power
7. Electrolysis of Water Using Simple Carbon Rods
8. Are Alkaline Fuel Cells Obsolete?

The course used hands-on, cooperative, and problem-based learning activities to create an active environment. A UST Bush Grant[7] was used to purchase several small PEM fuel cells, solar panels, electrolyzers and other laboratory hardware. Students were given questions to answer, but limited laboratory guidance. Students worked in groups of three to figure out an experimental protocol to answer the question. Some of the sample questions are provided in Table V.

Table V. Examples of Laboratory Questions used in Fuel Cell Engineering

A. What is the characteristic curve of a fuel cell?
B. What is the impact of internal resistance on the characteristic curve?
C. What is the impact of the catalyst load on the characteristic curve?
D. Should solar modules be connected in series or in parallel? Is there an ideal angle of incidence?
E. How does methanol concentration affect the characteristic curve of a methanol fuel cell? Is there an optimal concentration?
F. What is meant by fuel cell efficiency?
G. Should fuel cells be connected in series or in parallel?

Assessment

Students were graded by equally weighing, class participation (25%), their laboratory notebook (25%), their student led lecture and discussion (25%), and their design of experiment (25%). To measure the attitudinal effect of an open learning environment on the students, the students' expectations at the start of the semester and at its conclusion were assessed through a survey administered before and after the course. The student attitudinal response was overwhelmingly positive. Students felt that they had learned and understood a large amount of material.

In the spring of 2004, the assessment vehicle will be strengthened. A more quantitative approach shall be applied to ascertain the level of technical retention. The results of the peer assessment of the student led lecture and discussion were mixed. The ratings were disproportionately high, with most students reluctant to grade their peers with any score lower than a 3.0. The laboratory notebooks were of mixed quality at the beginning of the class. Tough mid-term laboratory grades and the input of a professional engineering consultant raised the level of work output significantly. The design of experiment proposals were of high technical quality. The use of an actual 'request for proposal' gave the students firm guidance and a feel for the competitive nature of real world proposal writing.

Summary

The course had excellent results. The students believed that they had learned a great deal about fuel cells, how to gather and synthesize information and as an added bonus, write a proposal. An interactive atmosphere in the classroom created a high level of enthusiasm and motivation in the students. Students enjoyed learning by discovery. The only major complaint from the students was that the equipment in the laboratory could have been of higher quality. Every effort will be made to upgrade the equipment for future courses.

References

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Biographical Information

CAMILLE GEORGE

Camille George is an Assistant Professor of Mechanical Engineering at the University of St. Thomas. She teaches Thermodynamics, Heat Transfer and Fluid Mechanics. She received a B.A. from the University of Chicago, a B.S. and M.S. from the University of Illinois at Chicago and a Ph.D. from the University of Minnesota. She worked several years as an engineer for Ingersoll-Rand and Martin-Marietta before obtaining her doctorate. Her current interests are in the areas of fuel cells, ethics and humanitarian engineering.