The Use of Energy Modules as a Mechanism to Introduce Sustainable Engineering and Improve Retention of Chemical Engineering Undergraduate Students at Mississippi State University

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Abstract – In our recent economic times, chemical engineering departments are faced with the need to improve retention to justify appropriate use of state and federal funding. At Mississippi State University, we are investigating ways to spur student interest using active learning methods as a means to improve retention and student interest in chemical engineering as a profession. This is being accomplished through the use of energy modules, many of which are applied to hydrogen production or hydrogen use in fuel cells. The introduction of energy technology provides us with a mechanism to apply the chemical engineering fundamentals to a broad problem in sustainable energy production and use. Since most chemical engineering students want a career where they can help others, the sustainability theme immediately gets their attention.

Keywords: Energy, sustainability, retention, active learning, fuel cells and hydrogen production

BACKGROUND AND MOTIVATION

Research and development in sustainable energy sources has been a focus of research and development activities in the last few years, as part of energy platforms of both Republican and Democratic politicians at the national and state levels. Within the field of chemical engineering, such advances are often challenging to incorporate into the curriculum as textbook content often lags behind research advances. It has been shown that the development of modules can allow for a drop-in implementation of educational content in emerging areas into the classroom. In this paper, we will report how we are integrating energy modules as a way to drop-in sustainability topics into the existing chemical engineering curriculum.

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In the summer of 2006, J. Keith initiated a collaboration with Prof. Scott Fogler of the University of Michigan and Prof. Don Chmielewski of the Illinois Institute of Technology. Throughout the years, this “Fuel Cell Curriculum Development Project” has been partially funded by the CACHE Corporation (Computer Aids for Chemical Engineering), the United States Department of Energy, Michigan Technological University, and Mississippi State University. The curriculum has been outlined by Keith et al. in the literature [1].

Since the inception of this project, there have been nearly four dozen modules in chemical engineering, over two dozen modules in mechanical engineering, and over a dozen modules in electrical engineering developed. The modules are available at: http://www.che.msstate.edu/pdfs/fuel_cell_curriculum/about.html with links to the separate curricula from that page. The chemical engineering modules are listed in Table 1. Although not all modules are used in this study, they are listed here for completeness.

Table 1. Chemical Engineering Modules Arranged by Course
(Modules are located at: http://www.che.msstate.edu/pdfs/fuel_cell_curriculum/index.html)

Introductory Material:
Overview of Hydrogen Energy and Fuel Cells
Fuel Cell Sizing Made Easy (Knovel Engineering Cases)
The Short-Term Hydrogen Economy: Fueling Fuel Cells (Knovel Engineering Cases)

Material and Energy Balances:
Heat of Formation for Fuel Cell Applications
Material Balances in a Solid Oxide Fuel Cell
Energy Balances in a Solid Oxide Fuel Cell
Generation of Electricity Using Recovered Hydrogen
Material Balances in Fuel Cell Systems
Heats of Reaction and Energy Balances in an SOFC

Thermodynamics:
Equation of State for Hydrogen Fuel
Equilibrium Coefficient and Van’t Hoff Equation for Fuel Cell Efficiency
Fuel Cell Efficiency
Vapor Pressure / Humidity of Gases
Nernst Equation

Fluid Mechanics:
Pressure Drop in Fuel Cell Bipolar Plate Channel
Finite Difference Method for Flow in a Fuel Cell Bipolar Plate
Compressor Sizing and Fuel Cell Parasitic Losses

Heat and Mass Transfer:
Conduction and Convection Heat Transfer
Microscopic Balances Applied to Fuel Cells
Diffusion Coefficients for Fuel Cell Gases
Conduction, Convection, and Radiation Heat Transfer in a Solid Oxide Fuel Cell

Kinetics and Reaction Engineering:
Tafel Equation and Fuel Cell Kinetic Losses
Hydrogen Adsorption and Catalyst Surface Coverage
Pressure Drop in a Water Gas Shift Reactor
Water Gas Shift Reaction in a Palladium Membrane Reactor
Equilibrium Simulation of a Methane Steam Reformer
Reaction Kinetics in a Solid Oxide Fuel Cell

Reactor Design Applied to a Solid Oxide Fuel Cell

Separations:
Hydrogen Purification
Air Separation for Coal Gasification
Hydrogen Production by Electrolysis with a Fuel Cell
Hydrogen Production by Natural Gas Assisted Steam Electrolysis

Process Safety and Process Design:
Stoichoimetric Analysis of Fuel Combustion
Energy Value of Fuels
Hydrogen Production Cost
Fuel Energy Cost and Energy Density
Hydrogen Flammability
Theoretical Fuel Consumption and Power
Unisim Modeling of a Proton Exchange Membrane Fuel Cell
Unisim Modeling of a Solid Oxide Fuel Cell

Materials Science and Engineering:
Ion and Electrical Conduction in a Solid Oxide Fuel Cell
Non Steady-State Carbon Diffusion in Solid Oxide Fuel Cell Interconnects
Mechanical Failure of Solid Oxide Fuel Cell Electrolyte

It is noted that some modules that fit within the generic classification of "general energy analysis" are co-listed with some of these courses. These modules are focused primarily on hydrogen as an energy carrier and also on energy consumption, energy efficiency, battery energy, solar energy, and wind energy. Efforts are underway to continue to develop additional modules in alternative energy. The published modules are listed in Table 2.

Table 2. Additional Energy Engineering Modules Arranged by Topic (and Corresponding Website)

General Energy Analysis (http://www.che.msstate.edu/pdfs/energy/generalenergy.html)
Energy Consumption Analysis
Energy Efficiency Analysis
Energy Emissions Analysis
Battery Energy Analysis
Battery / Fuel Cell Vehicle Range
Solar Energy Analysis
Wind Energy Analysis
Power and Energy Analysis of Transient Driving Schedules

Coal Energy (http://www.che.msstate.edu/pdfs/energy/coal.html)
Material Balances on CO_2 Absorption / Stripping Process

Solar Energy (http://www.che.msstate.edu/pdfs/energy/coal.html)
The Power of Solar Energy
Solar Water Heating

MODULE DESIGN

To be most effective in the classroom as well as out of class learning experiences, each module consists of a problem motivation, example problem statement, example problem solution, home problem statement, and home problem solution (home problem solution available to instructors). The modules also have additional information that lists the chemical engineering course that the problem can be used in, correlated to specific sections of popular textbooks to aid instructors in identifying when an individual module may be particularly beneficial to enhance student understanding and learning of course concepts.

Similar compilations of instructional modules, developed for ease of implementation in engineering courses, are available. As a point of reference, online modules can be found at the bioengineering educational materials bank: (http://www.bioemb.net) the materials digital library pathway: (http://matdl.org), the Massachusetts Institute of Technology open courseware site (http://ocw.mit.edu), and the Multimedia Educational Resource for Learning and Online Teaching site (http://www.merlot.org).

The modules can be quickly downloaded and used in any chemical engineering undergraduate course. The most common way that the modules have been incorporated into instruction is:

- There is a short lecture on a chemical engineering (or energy) topic
- The students are given a module to serve as an in-class problem
- The students work through the example problem in the module during class
- The students begin solution of the homework problem during class
- The instructor circulates around the room and assists students if they have any questions
- The homework problem is due at a future class meeting

Assessment of the modules in elective courses was reported by Keith et al. [2-3]. Overall, students found the module format (especially including an example problem) to be very helpful to them in designing alternative energy / fuel cell related systems.

USE OF MODULES AT MISSISSIPPI STATE UNIVERSITY

Table 3 identifies the chemical engineering courses in which the energy modules are being used or are planned for use. The intent is to highlight sustainable energy concepts during each year of undergraduate study. As an example, the use of the modules during Fall 2011 will now be described.

Table 3. Chemical Engineering Courses

Course Number	**Title**	**Year / Semester of Curriculum**
CHE 1101	CHE Seminar	Freshman / Fall
CHE 2213	CHE Analysis	Freshman / Spring
CHE 2114	Mass & Energy Balances	Sophomore / Fall
CHE 3223	Mass Transfer Operations	Junior / Spring
CHE 4113	CHE Reactor Design	Senior / Fall
CHE 3413	Engineering Materials	Senior / Fall
CHE 4223	Process Instrumentation and Automatic Control	Senior / Spring
CHE 4990	Hydrogen Energy Fundamentals	Elective

In CHE 2114, the module on material balances in fuel cell systems was used as a homework problem. This course uses the textbook Elementary Principles of Chemical Processes by Felder and Rousseau [4]. The module was introduced while chapter 4 of the text was being covered, after the concept of extent of reaction was taught. Anecdotal comments from the students suggested that the problem was very interesting in that it showed a new application of the fundamentals that they were learning in class. Furthermore, many students enjoyed the challenge of the problem and the fact that it integrated all aspects of what they had learned previously in the course. Also, some students felt they were finally able to grasp the concept of extent of reaction after solving this problem. Finally, students liked having an example problem to refer to as they completed the module home problem. Some students did indicate a need for additional background in fuel cells. Some also indicated that they were unprepared for a problem of this difficulty level and/or the use of matrices (which is not required to solve the module home problem, but is demonstrated in the example problem).

In the Engineering Materials (CHE 3413) course, portions of the module on non steady-state carbon diffusion in solid oxide fuel cell interconnects were used as an examation problem. The text used in this course is Material Science and Engineering: An Introduction, by Callister and Rethwisch [5]. In lectures leading up to the exam, an extensive discussion of diffusion and applications of Fick's second law for unsteady state diffusion in a semi-infinite domain were provided. When the surface concentration is held constant, the application of boundary conditions and the initial condition yields the solution involving the complementary error function.

A journal article was posted to the student-accessible myCourses website and they were required to read the article prior to the class discussion. This journal article [6] provided the basis for discussion and covered a wide variety of interesting applications of carburization and decarburization including: 1) the high rate of carburization by reduction of CO and H_2; 2) the insignificant rate of decarburization by H_2; 3) the disproportionation of CO; and 4) a comparison of the rate of decarburization of CO_2 and H_2O at the specified temperature. Also examined were surface hardening of a steel gear and carburization of an FCC iron alloy. These cases were selected as model systems for determination of treatment temperature as well as diffusion time required to achieve a given composition at a specified distance from the surface of the steel gear. These applications involved the same knowledge as the energy module. The energy module provided the students with an emerging application of this timeless analytical solution for the diffusion PDE for solid oxide fuel cell interconnects. Overall, the students performed well on this graded component.

In CHE 4113, two modules were used. The first module employed focused on estimation of the pressure drop in a water-gas shift reactor. In this module, students were given an example problem that showed how to perform pressure drop calculations in a laboratory reactor. In their homework assignment, the students needed to apply the same technology to an industrial reactor. This enabled them to see the differences in the order-of-magnitude of the pressure drop as well as which terms in the pressure drop equation were important for each scale. In addition, in many of the problems from the Elements of Chemical Reaction Engineering text by Fogler [7] involving the Ergun equation, the parameter, α, which quantifies pressure drop, was simply provided, and students did not have to actually evaluate it. Thus, the experience they obtained in performing the calculations for the energy module will be beneficial should they have to evaluate pressure drop in an industrial reactor once they are working as chemical engineers. The α value won't simply be given in such a situation; students will have to use porosity and superficial mass velocity along with fluid and particle properties and system dimensions to calculate the pressure drop parameter. They liked actually performing the calculations, making sure that they had appropriate units and conversions and using the end result to evaluate the reactor performance and pressure drop.

The second module used in CHE 4113 was the module discussing site balances to determine hydrogen adsorption and catalyst surface coverage in a fuel cell application. In class lectures on catalysts and catalytic processes, the steps in catalytic reactions as well as developing an expression for the catalytic rate given a proposed mechanism with surface reaction being the slowest step were provided. Single-site and dual-site adsorption processes were discussed as were dissociative and molecular adsorption and their governing rate expressions developed. Thus, students were able to readily integrate the Tafel reaction where hydrogen undergoes dissociative adsorption into their existing knowledge structure. In the module home problem, students were asked to determine surface coverage by hydrogen on the catalyst surface at a particular current density, as well as properly interpret their answer. Discussions in class regarding mass-transfer limited processes as well as kinetically-controlled processes were drawn upon as they were able to correctly interpret their calculated answer to the module home problem.

In general, it is noted that the instructors liked having access to new problems since many of the problems in the textbooks have been used in class before and the current students have access to scoop files or the solution manuals. We are currently in the process of developing a course survey and seeking IRB approval to conduct the surveys during the spring semester. As a final note, in Spring 2012, we will continue to use these modules in our courses.

This will include extensive use in the elective course hydrogen energy fundamentals. An outline for the course is shown in Table 4.

Table 4. Tentative Course Outline for Hydrogen Energy Fundamentals

Week	**Topic**
1	Course Outline; History of Energy Production
2	Energy Sources, Emissions, Capacity
3	Electric / Hybrid Electric Vehicles
4	Fuel Cells and Fuel Cell Vehicles – general concepts
5	Fuel Cells and Fuel Cell Vehicles – mass balances
6	Hydrogen from Natural Gas: Steam Reforming
7	Review and Quiz
8	Hydrogen from Natural Gas: Hydrogen Purification
9	Hydrogen from Coal
10	Hydrogen from Biomass
11	Hydrogen from Electrolysis / Hydrogen from Wind
12	Hydrogen from Solar Energy
13	Review and Quiz
14	Hydrogen from Nuclear Energy / Hydrogen Public and Government Policy / H_2 Economy
15	Student Presentations

Conclusions and Future Directions

This paper has described the use of energy modules in the chemical engineering curriculum at Mississippi State University. These modules are being integrated throughout the core courses in the freshman, sophomore, junior, and senior years and also in an elective on hydrogen energy. The intent of the modules is multi-faceted. The modules show a connection between traditional chemical engineering fundamentals and applications to real world energy problems. This includes showing the impact that a chemical engineering education can have on both domestic energy independence and on worldwide energy availability, as well as in the stewardship of energy resources. We plan on assessing the impact of sustainable energy course content on student interest in chemical engineering as a career and in student retention to graduation.

References

[1] Keith, J. M., Crowl, D. A., Caspary, D., Allen, J., Naber, J., Meng, D., Mukherjee, A., Lukowski, J., Meldrum, J., and B. Solomon., “Interdisciplinary Minor in Hydrogen Technology at Michigan Technological University,” ASEE Conference Proceedings (2010).

[2] Keith, J. M., Crowl, D. A., Caspary, D., Allen, J., Meng, D., Naber, J., Mukherjee, A., Lukowski, J., Meldrum, J., and B. Solomon, “Hydrogen Curriculum at Michigan Technological University,” ASEE Conference Proceedings (2009).

[3] Keith, J. M., Lopez Gaxiola, D., Crowl, D. A., Caspary, D., Mukherjee, A., Meng, D., Naber, J., Allen, J., Lukowski, J., Solomon, B., Meldrum, J., and T. Edgar, "Development and Assessment of Energy Modules in the Chemical Engineering Curriculum," ASEE Conference Proceedings (2011).
[4] Felder, R. M. and Rousseau, R. W. Elementary Principles of Chemical Processes. 3rd Edition. Wiley, New York, NY, 2005.
[5] Callister, W. D. and Rethwisch, D. G. Materials Science and Engineering: An Introduction. 8th Edition. Wiley, New York, NY, 2009.
[6] Miller, Dale C."Accelerated Carburizing through Special Control of Furnace Atmosphere and Reactions, *Industrial Heating*, BNP Media, Pittsburgh, PA: August 1982.
[7] Fogler, H. S. Elements of Chemical Reaction Engineering. 4th Edition. Prentice Hall, Upper Saddle River, NJ, 2009.

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