Preparing Students to Succeed in the Global Energy Industry

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Abstract — *The purpose of this paper is to explain why a course for energy engineers is necessary and to describe the design of an energy engineering course for technical majors. The course helps technical majors avoid the trap of being so specialized in one discipline that they cannot appreciate their specialty in either a broad technical or societal context. The course curriculum is described and justified; competencies and learning outcomes are identified; and the integration of the course in existing engineering programs is discussed.*

Index Terms — *Course curriculum, energy engineering, energy fundamentals, learning outcomes*

INTRODUCTION

Many experts believe that oil production will peak in the first quarter of the 21st century [1]. The oil production peak will be followed by a decline despite an increasing demand for energy. The combination of increased demand and reduced supply will lead to a significant increase in the price of oil. According to this scenario, other sources of energy will begin to replace the increasingly expensive oil. The dominance of oil in the current energy mix will not continue.

Some companies have responded to new market realities by transforming themselves into energy companies. These companies include oil and gas companies and utilities. For example, the Texas-based energy company TXU generated 19,000 MW power "with a fuel mix of coal/lignite, natural gas/oil, nuclear power and wind" [2]. The Royal Dutch/Shell group includes member organizations, such as Shell Petroleum and Shell Renewables, that provide oil, gas, wind and solar energy [3]. The trend to form energy companies that manage a mix of energy components is driving the development of an emerging energy industry. The new energy companies will need to employ professionals that understand and appreciate the role of a variety of energy components in the energy mix. This creates both a challenge and an opportunity for educators: how do we prepare this new breed of engineer – an energy engineer?

Thumann and Mehta [4] define energy engineering as a profession that "applies scientific knowledge for the improvement of the overall use of energy" (pg. 1). Professionals in energy companies will need to understand and appreciate the role of a variety of energy components in the energy mix. They will need to understand how energy can be transformed from one form to another form, and the consequences of the transformation. They will need to be able to identify and solve problems in the acquisition and environmentally acceptable use of several energy components. To achieve these learning outcomes, a fundamental change is needed in the education of budding energy engineers.

Energy engineers today are individuals with a variety of technical backgrounds, ranging from the sciences such as physics and geology, to engineering, such as electrical, mechanical and petroleum engineering. Students in technical majors are usually advised to focus on their major and closely related fields following preparatory classes in mathematics and physics. Limited interaction between disciplines can lead to a narrow specialization that makes it difficult for technical majors to appreciate their areas of interest in either a broad technical or societal context.

In the following, we describe the design and implementation of an energy engineering course for technical majors. The course helps technical majors avoid the trap of being so specialized in one discipline that they cannot appreciate their specialty in either a broad technical or societal context. The course curriculum is described and justified; competencies and learning outcomes are identified; and the integration of the course in existing engineering programs is discussed.

COURSE DESIGN

The objective of this project has been to develop a 1 semester, 3-credit hour energy survey course for undergraduates in technical majors. The energy course is designed to introduce students who have completed college level engineering physics and calculus to the fundamentals of energy engineering. The course serves as a bridge between learning the fundamentals of science and mathematics in the freshman or sophomore year to specializing in a particular discipline in upper division undergraduate and graduate programs in science and engineering. The place of the energy survey course in a typical science or engineering curriculum is illustrated in Figure 1.

Energy Course Curriculum

The energy course curriculum is summarized by the topics listed in Table 1. After introducing the historical context of 21st century energy, we present the concept of energy transformations. The modern system of distribution of energy in the form of electricity is then discussed, followed by a review of heat and thermodynamic concepts. This background sets the stage for the study of specific energy types.

The first energy type to be considered is geothermal energy because it allows us to introduce basic concepts of planetary formation and geology. The discussion of planetary formation and geology explains the source of geothermal energy (why is the interior of the earth hot?). It is also an example of setting an energy source in the broad epistemological context that is represented by the United States National Academy of Sciences (U.S. NAS) content standards. The discussion of energy origins is especially valuable from a pedagogical point of view because it ensures that all of the students in the course are exposed to the leading theories of several sciences that have been identified by the U.S. NAS. Among these theories are Big Bang cosmology, the Kant-Laplace hypothesis, plate tectonics, the Oparin-Haldane hypothesis, and the synthetic theory of evolution. These theories provide a context that helps students understand mainstream ideas and competing ideas, such as the origin of fossil fuels based on the biogenic theory and the abiogenic theory.

Once geothermal energy has been studied, we consider fossil fuels, which provide the majority of energy consumed today. This is followed by a discussion of solar energy, nuclear energy, alternative energy (wind, water, biomass), and then hydrogen. To put the technical material in a social context, we discuss the role of energy in society, including economic and environmental considerations. Finally, the course ends with a discussion of energy forecasts and the trend toward a hydrogen economy.

Themes and Strands

The course has been developed as a set of thematic modules. Themes include electricity distribution, geothermal energy, fossil fuels, solar energy, nuclear energy, alternate energy, the hydrogen economy, energy and society, and energy forecasting. The modules may be taught in a team-teaching format by experts in each module, or taught by a single instructor. Although it might be pedagogically preferable to have a team of experts teach the course, team teaching can be a drain on the institution's resources, and some institution's may not have the expertise to facilitate a team-taught format. In our case, the course was taught by a single individual and guest lecturers provided supplemental enrichment. The course material has been designed to enable a single instructor to teach the course.

Technical strands run through the thematic modules to help prepare students for increasingly sophisticated concepts. For example, the Lagrangian is introduced in the introductory review of energy transformations and then used to discuss the development and interpretation of quantum mechanics and relativistic quantum mechanics using path integrals. Quantum mechanics is introduced using black body radiation as a model of solar radiation and the Bohr atom to discuss energy levels in atoms. Quantum mechanics is used to help the student understand energy levels and transitions between energy levels, covalent bonds, quantum tunneling (as in nuclear decay), and to explain the free electron theory of metals. The latter theory is useful for discussing the photoelectric effect and photovoltaics, which has applications in solar energy. Relativistic quantum mechanics is used to help the student understand the concept of mass-energy equivalence and develop a more sophisticated understanding of nucleosynthesis and nuclear energy (both fission and fusion). Combinations of technical strands are also used. For example, the origin and chemistry of life and the theory of plate tectonics provide much of the scientific basis for understanding the origin and accumulation of fossil fuels. The use of technical strands enables us to present the content of U.S. National Academy of Science content standards while the technical themes make it possible to demonstrate the relevance of the technical strands in a broad social context.

Module Learning Objectives

The successful outcome of the energy survey course described here is determined by what students know and are able to do. By the end of the course, students should know terminology, fundamental principles, and mainstream theories. Students should be able to solve a range of energy related problems, and understand issues associated with the science and technology of energy.

Several learning objectives are sought in each course module. The learning objectives include: acquiring knowledge; learning to analyze and interpret data; understanding system design; becoming familiar with outstanding scientific and engineering problems; understanding the ethics associated with different energy sources and their distribution; understanding the role of energy in a global and societal context; understanding the need for lifelong learning during a century of flux in the energy mix; understanding contemporary issues associated with energy; and developing skills for solving problems. These learning objectives are important elements of ABET EC2000 criteria.

Level of Presentation

The level of presentation has been determined by reviewing material from a variety of sources ranging from non-technical general science and technology survey courses to upper division textbooks for technical disciplines. Presentation materials and assessment tools were designed to further develop the technical skills of the student. Technical material is developed based on the assumption that a student has completed multivariable calculus and the first year of college physics with calculus. Exercises have been developed to date that range from simple to challenging, and are suitable for individuals, small groups, or classroom activities. One of our goals is to seek a balance between concepts and applications. Examples of applied technology, both actual and anticipated, for each energy source are described.

The course manuscript has been class tested at the Colorado School of Mines (CSM) and published by Elsevier-Academic Press [1]. Student evaluations were used to refine course materials. Students indicated what components of the course assisted them in learning, and what parts of the course could be improved. This feedback has been used for the continuous improvement of the course.

EXPERIENCE TO DATE

The course was first taught as a free elective for seniors during the Spring 2003 semester at the Colorado School of Mines [5]. It was taught for the second time during the Spring 2004 semester. It was co-listed as a free elective for either undergraduate students or graduate students. The Spring 2003 class was offered twice a week (Tuesday and Thursday afternoons) for 1.25 hrs each time, while the Spring 2004 class was offered one evening a week (Tuesday). The evening time was selected to encourage enrollment from departments around campus and from the local community.

The student population in both semesters consisted of students from many parts of the world, including the Middle East, Africa, Latin America, and Europe. Approximately half of the students were from North America. Approximately one third to one half of the students speak English as a second language (ESL). All of the students had the pre-requisite technical background. Students ranged from a second semester sophomore to Ph.D. candidates. Most of the students were seniors or graduate students and had engineering, geoscience or mineral economics backgrounds. Graduate students were expected to perform additional work for graduate credit. Based on experience in the Spring 2003 semester, the discussion of nucleosynthesis was considered an optional topic and was not required for undergraduate credit in the Spring 2004 semester; students seeking graduate credit were expected to read and summarize the nucleosynthesis chapter, and prepare a report on the status of an energy source of interest to the student.

New material was covered using the following procedure: students were expected to read each new chapter before class; a lecture would then be given highlighting concepts in the chapter; students were then asked to work in small groups to answer a few questions about the lecture and reading material; the questions and answers were then discussed by the class as a whole. In many cases, the lectures were given by guest speakers.

In addition to lectures, homework assignments, and in-class questions, students were asked to complete a Perspectives exercise. The Perspectives exercises can be used as study guides because they help students identify parts of the material that were needed to answer "big picture" questions. More importantly, the Perspectives exercises encourage students to tie together apparently disparate material.

Tests were designed to test student comprehension and problem solving skills (what students know and are able to do). Tests included true/false statements, questions, and problems. Three tests were given: after chapters 1 – 6, chapters 7 – 11, and chapters 12 – 15. These groupings represent related material. Student performance on tests in both classes has generally shown that grade level is not as important as preparation. The distribution of student test scores was comparable for undergraduate and graduate students. Students with the best scores were also the students who participated regularly in class and were best prepared, as measured by performance on homework.

A final survey was conducted at the end of the course. The survey was a questionnaire that asked students to comment about the course and course materials. Specific comments about the Spring 2003 course are presented in Reference [5].

The questionnaires in both the Spring 2003 course and Spring 2004 course have shown general student support for course material and pedagogical technique. Several students commented that the course was a good overview that tied together much of the technical material that they had been exposed to during their academic careers. Students in both courses said they would recommend the course. The most common concern expressed by students was that they would like more time for some of the topics in the course. For example, one student wanted more discussion about energy forecasts and economics. The choice of topic depended on the student's interest and varied from one student to another. As a rule, students realized that there was a limit to what could be covered in such a broad area. One typical attitude was expressed by the comment that the course "can show where the energy business has been, where it might go, and how we fit in the mix." Another student noted that the material was presented in depth, but students were "tested over only relevant issues, thus you can really take away a broad-based concept of energy." The student went on to say that the course would help his career because it "has helped me consider other views for energy solutions and opened my eyes to future scenarios."

CONCLUSIONS

The course described here presents an integrated overview of energy sources that will be available for use in the 21st century. The course is designed for technical majors rather than the general student population because it presumes knowledge of college level engineering physics and calculus. This allows the class to study concepts at a more sophisticated level than courses that are designed to satisfy the general science requirement for undergraduates. Students gain familiarity with the resources available to supply energy to both developed and developing nations. Student feedback has shown that this broad perspective stimulates student interest in an emerging energy industry, provides future engineers with an expanded knowledge base and an awareness of trends that are expected to affect their lives during the course of their careers as energy professionals.

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FIGURES AND TABLES

TABLE 1
ENERGY COURSE CURRICULUM

Chapter	Topic	Module
1	Introduction	Introduction
2	Power Generation and Distribution	Background
3	Heat Engines and Heat Exchangers	
4	The Earth and Geothermal Energy	Geothermal Energy
5	Origin of Fossil Fuels	Fossil Energy
6	Fossil Energy	
7	Solar Energy	Solar Energy
8	Solar Electric Technology	
9	Mass – Energy Transformations	Nuclear Energy
10	Nucleosynthesis (graduate credit)	
11	Nuclear Energy	
12	Alternate Energy – Wind and Water	Alternate Energy
13	Alternate Energy – Biomass and Synfuels	
14	Energy, Environment, and Economics	Energy and Society
15	The 21st Century Energy Mix	Forecasts

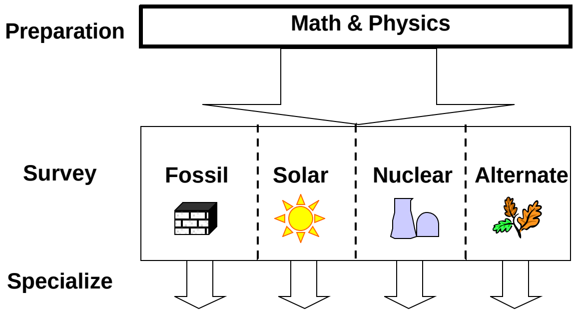

FIGURE 1
ENERGY ORIENTED CURRICULUM WITH AN ENERGY SURVEY COURSE