THE DESIGN, IMPLEMENTATION, AND ASSESSMENT OF A NEW CAPSTONE COURSE AIMED AT SCIENCE EDUCATION MAJORS

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Abstract

This paper rationalizes the selection of the concept of energy as the central theme of a new capstone course aimed at science education majors. It describes the goals of the course and the activities that preceded the course design and led to the selection of the topics, of the educational materials, and of the teaching methodologies. It presents a sequential description of the manner in which the conceptual knowledge of energy was to be developed. The specific experiments, interactive demonstrations and other educational materials utilized for the conceptual development of the concept of energy in context are described and referenced. The course objectives are described, as well as the instruments utilized to assess student learning. It also presents the activities utilized to assess the course, in addition to the modifications made to the course syllabus based on this assessment.

Introduction

The reform of teacher preparation programs must be harmonized with the reforms being carried out at the K-12 level. The communication among all the sectors involved in the science and mathematics reform is mandatory in order to ensure the same vision and clear and complementary objectives. For this reason, we started the reform of our teacher preparation programs, by first looking at the K-12 science and mathematics reform that had been going on for several years. We found that important documents have been developed; one of which, the Science Content Standards, was of particular interest. These local science content standards are based on macro concepts that cut across all the scientific disciplines, thus giving a more integrative and interdisciplinary approach to the teaching of science. The seven local Science Content Standards are: (1) The Nature of Science, (2) The Structure and Organizational levels of Matter, (3) Systems and Models, (4) Energy, (5) Interactions, (6) Conservation and Change, and (7) Science, Technology, and Society. Of these standards, we selected Energy as the main theme of a capstone course because it is a fundamental and important concept that teachers find difficult to teach [1-3]. Furthermore, examples of the concept of energy are very familiar and relevant to our students in the areas of chemistry, physics, biology, and earth sciences. While Energy was the concept selected for development in this course, Energy is not the only Science Content Standard we wanted to address. The course aimed to cover some aspects of all the Standards, especially The Nature of Science, Systems and Models, Interactions, Conservation and Change, and Science, Technology, and Society.

In the design of the capstone course, we took into consideration that it would be taught at an advanced level where students could bring together the knowledge and skills developed during the courses of the core curriculum in a coherent, meaningful, relevant, and applicable way. Students would have prior knowlèdge of the fundamental concepts of energy in the different areas of science.

We considered that the capstone course could help students develop their ability to transfer knowledge from one science discipline to another. It could also give them the opportunity to apply different teaching methodologies and strategies in a teaching situation in which they will receive constructive criticism from peers and faculty. In addition, a capstone course could give them the opportunity to assess their level of understanding of fundamental concepts, help them identify their misconceptions, and motivate them to work on improving their knowledge and ability to develop conceptual understanding with their students, once they become teachers.

Designing the Course

The first step in the conceptualization of the capstone course was the selection of energy as the central theme. The second step was to select the topics to be studied. These had to be relevant and already discussed in the introductory chemistry, physics and biology courses; major topics that encompass elements from the different disciplines. We understood that this topic selection would be conducive to an increase in students' motivation to gain a more in-depth and meaningful understanding of the concept of energy. Before making the final selection, we consulted professors in introductory science courses to identify the context in which they covered the forms, manifestations, and transformations of energy. Small, informal meetings were held with physics, biology, chemistry, and earth science professors. We asked them to identify the sections in the textbooks where energy concepts were discussed. We studied these materials to gain an understanding of students' previous knowledge of energy. Research in an extensive library and on the Internet was also conducted to identify websites of energy-related sources. The following topics were selected to be covered in the course: the development of a high-energy sports drink; human metabolism; energy saving light bulbs; photosynthesis; cellular respiration; alternatives to fuel energy; the occurrence of earthquakes; and, global warming and the formation of hurricanes. These topics are relevant to daily life, fundamental to the scientific understanding of our world, and discussed in previous courses.

The third step was to select the course's curricular materials. Chemistry, biology and physics professors that teach the introductory courses recommended curricular materials that could be used to explore, experiment with, or apply the fundamental concepts. Some of these professors designed new experiments and activities. Again, we researched the Internet and the library for books, videos, CDs, case studies, articles, and laboratory experiments related to the selected topics, and made a selection of these materials. We also developed interactive demonstrations and identified short investigations for students to perform.

Another very important activity was the selection of the teaching methodologies and strategies that would be used in the course. We decided to use the inquiry and constructivist approach and to model scientific research. We felt that by doing so we would be promoting active learning, critical analysis, and in-depth understanding of the underlying concepts, as well as addressing the other content standards. The course was conducted as a workshop to promote student participation and continuous self-assessment of knowledge. The professor introduced the fundamental concepts by modeling the best content-specific teaching methodologies and the proper use of educational technology. Group presentations, based on the application of conceptual knowledge to the solution or interpretation of problems encountered in real life situations, were an integral part of the course. These presentations gave students the opportunity to use new technology and to apply different teaching strategies to a class composed of peers and professors, who provided immediate feedback on their teaching strategy and selection of materials.

Another very important aspect was to decide on the previous science courses that students should have taken. We felt that in order to develop an understanding at the microscopic level of the macroscopic manifestations of energy, students needed to know the principles that govern the physical and chemical aspects of matter and the role of plants and animals in ecological systems. At our university, this knowledge is gained in the following two-semester courses: *General Chemistry*, *General Physics*, and *General Biology*. In addition to requiring these basic science courses, we also decided to require the first semester of *Organic Chemistry*, specifically because it introduces infrared spectroscopy and the oxidation/reduction reactions that occur in the metabolism of organic molecules in nature.

The Course Sequence

The sequence of the topics discussed in the course and how they are interrelated is presented in Figure 1 and Table 1, respectively. Initially, the basic principles of kinetic and potential energy were introduced. They were elaborated by means of semi-Socratic discussions and hands-on group activities where students needed to delve into their conceptual understanding instead of the mathematical algorithmic manipulation of equations. Familiar and simple examples were extracted from everyday life and then analyzed and studied in depth, from the macroscopic to the molecular level. Using this same teaching methodology, we developed more complex aspects of energy, such as heat transfer, absorption and emission of electro-magnetic radiation, and conservation and transformation of energy. As the course progressed, topics from biology, physics, chemistry, and earth sciences were discussed and analyzed building on the deep conceptual understanding developed early in the course. The principle activities utilized to introduce and develop the concepts related to energy to a very deep level of conceptual understanding are included in the table. As part of this process, groups of students were assigned special projects that required small investigations. Students presented the results of their investigations, emphasizing the energy principles relevant to their project. The topics of some of these investigations are included in Table 1.

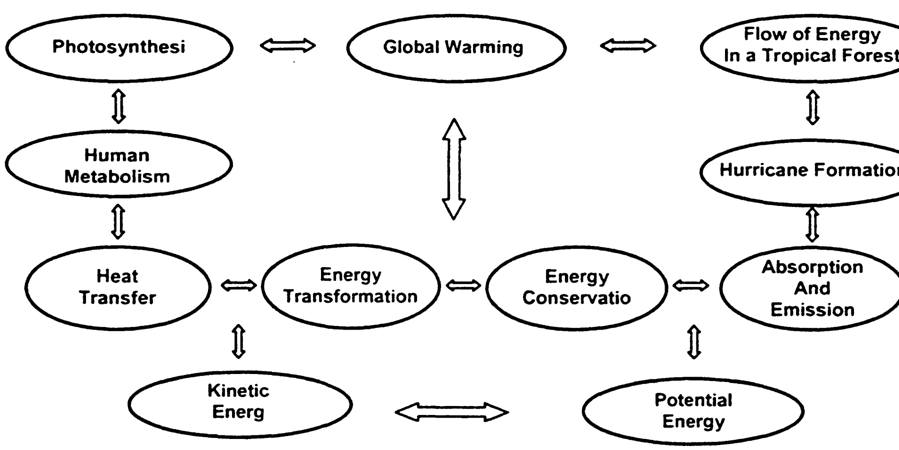

Figure 1. How are topics interrelated?

Table 1. The sequence of topics and examples of activities carried out to develop the concepts.

Topic	Emphasis	Activities
Potential and Kinetic Energy	Types of Energy Interchangeability and conservation	Demos: Bouncing ball; free fall of a piece of paper in flat and crumpled forms; storing and releasing energy in a mousetrap. Videos: Free fall of a vault jumper; a person in weight training; and, the free fall on the Moon of two objects with same mass but different shapes [4]. Student Investigation: Should we use high efficiency bulbs? Why are they more efficient than conventional bulbs? Student Investigation: Based on your weekly caloric intake and exercise, will you gain weight eventually?
Heat and Heat Transfer	Difference between heat and temperature Conduction of heat Specific heat	Joule's experiment of the mechanical equivalent of heat [5]. Demo: Heating of naphthalene to its melting point. Experiment: Determination of the Heat of Fusion of ice [6]. Experiment: Determination of the specific heat of two objects (metal and rubber) with the same mass. Experiment: The determination of the temperature of water heated above 50° C with a thermometer that reads from 0-50° C [7].
Heat Transfer	Conduction, convection, and radiation	Demo: The burning candle [8] experiment: Selection of the most efficient cooking pot amongst three of different metal compositions [9].
Capture of Radiant Energy from the Sun	Absorption of ultraviolet, visible, and infrared light Why is photosynthesis a spontaneous process? Storage of energy in chemical bonds	Experiments: Absorption of visible and infrared light by various atmospheric gases [10]. Experiments: Identification of compounds that absorb radiation in the processes of photosynthesis, hurricane formation, and global warming. Field Study: Flow of Energy in a Tropical Ecosystem [1]. Student Debate: According to Scientific Research - Is Global Warming Real?
Human Metabolism of Fats, Proteins, and Carbohydrates	Transformation of energy Chemical bonds as a source of energy	Student Investigation: Why are carbohydrates a faster source of energy than proteins or fats? [11] Student Investigation: What is the role of each of the components of the sports drink Gatorade®?[12]

[1]Unpublished exercise by Patricia Burrowes, Ph.D., Assistant Professor in the Dept. of Biology, University of Puerto Rico, Río Piedras.

What are the Course's Objectives?

We are aware that upon graduation these students will teach their students the fundament ideas of the Energy standard. In order to do so, they have to develop an in-depth conceptu understanding of these ideas and they must be able to carry out activities that are conducive understanding. With this in mind, the following objectives were developed. After completing t course, students should be able to:

- Base their understanding of energy on the few universal laws that describe and explain the manifestations of energy;
- Distinguish between the forms of energy: potential (gravitational, chemical, elastic, electromagnetic, and mass) and kinetic (heat, moving objects, sound, and waves) in various complex contexts;
- Identify the modes in which the forms of energy are manifest in chemical bonds, electromagnetic waves, photosynthesis, and atmospheric phenomena;
- Determine whether on-line information is valid;
- Lead a discussion on a scientific topic utilizing critical thinking skills, valid data, respect for opponents' ideas, and ethical principles;
- Describe at an atomic and molecular level, the physical, chemical, and biological changes that occur during the transformation of energy;
- Predict the spontaneity of the transformations of energy;
- Estimate and compare the magnitude of the forms of kinetic and potential energy;
- Describe the combinations of the forms and transformations of energy that occur in complex processes such as photosynthesis and hurricane formation;
- Apply conceptual knowledge of energy to the solution or interpretation of problems encountered in real life situations.

How Did We Assess Student Learning?

We developed a strategy to assess the impact of the course based on students' progress. The grade was skewed to give more weight to students' progress in the mastery of the fundamental concepts as they were developed in an ascending spiral. Weekly quizzes, laboratory reports, presentations, and a debate were used in the assessment process. Pre- and post-concept maps served the same purpose of assessing depth of conceptual understanding and student ability to establish interconnections among disciplines. A final exam that required in-depth analyses of all the energy transformations involved in familiar complex situations—for example, the generation of electrical energy from flowing water—was part of the assessment. When we analyzed students' answers, we found that their conceptual understanding had improved considerably. To our disappointment, we also found that some basic misconceptions still lingered, in agreement with other results reported in the literature on conceptual change [13-16].

How Was the Course Assessed?

We developed various instruments to assess the impact of the course in the development of students' conceptual understanding of energy principles. Initially, we probed the knowledge students brought from other courses and their attitude toward the study of science. The assessment of conceptual understanding was carried out with a concept map, and the attitude toward science with a modified version of the Maryland Collaborative for Teacher Preparation's questionnaire: *Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science* [17]. The initial concept map revealed very poor connections between basic concepts and their relationship to macro concepts in the areas of photosynthesis and the greenhouse effect. Quizzes were carefully prepared to assess the progress of conceptual understanding throughout the course. These quizzes were targeted to measure the level of attainment of specific objectives that we developed in the course in a spiral-ascending mode. Students were actively involved in the assessment process since they were well aware that this was a pilot course. After every three-hour session, we reflected as a group on the class experiences. In these reflections, students identified areas where they still had difficulty, topics that they found irrelevant, and areas that were not covered in the course but that they thought should be included. The teaching methodologies used were assessed in a similar manner. At the end of the semester, a post-conceptual map was administered and it revealed significant improvement in the comprehension of the interrelationship of the basic principles and the macro concepts studied in the course. A significant improvement was also observed in students' attitude toward learning science. The details of how we conducted this thorough assessment is the object of another article soon to be published.

Modifications

The information gathered led us to modify the course for the future in a variety of ways. We will not use a textbook and will refer students to selected chapters in books on physics [13], biology [18], biochemistry of metabolism [10], physiology [19], meteorology [20], and physical sciences [5]. We will supplement this material with articles from journals and websites [12, 21-30]. The sequence of topics will also change: radiation will be studied before photosynthesis; metabolism before the composition of Gatorade; and heat transfer on earth before hurricanes. In addition, we plan to eliminate topics such as alternative sources of fuel energy, earthquakes, and cellular respiration [31-33]. Based on the finding that some misconceptions on energy transformations persisted, we will include more hands-on activities. Although students were given guiding questions on which to base a debate on global warming, we found that this topic is so complex, and there is so much information, that it was difficult for students to focus on the main issues. We have made a selection of articles and have identified specific topics that students should address in their debate. Students will have this information to help them prepare for the debate. ■

Bios

Rosa Betancourt-Pérez is a professor in the Department of Chemistry at the University of Puerto Rico, Río Piedras. She teaches the organic chemistry course that the future science teachers must take and the capstone course which is the subject of this paper.

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