Bridging Science and Engineering: An Integrated Course for Non-Science Majors

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In recent years, landmark reports such as *Physics at the Crossroads* (1996) and *Shaping The Future* (1996) have identified disturbing trends in university physics education in the United States. In general, these reports have indicated that students completing introductory undergraduate physics courses often complete these courses inadequately prepared for future careers or further science study. Publications with a K-12 focus such as the *National Science Education Standards* (1996) and *A Nation at Risk* (1983) have identified several key recommendations for the enhancement of physics instruction. These recommendations are consistent with those made by *Physics at the Crossroads* (1996) and *Shaping The Future* (1996). The recommendations of these reports have included enhancing students’ 1) Conceptual understanding of physics, 2) Critical thinking skills, 3) Problem solving and scientific inquiry skills, 4) Enthusiasm for science and for learning.

In response to these recommendations, the College of Engineering and the Science Education program in the College of Education at The Pennsylvania State University collaborated to design an innovative course for non-science majors. Supported by the NSF-funded program ECSEL (Engineering Coalition of Schools for Excellence in Education and Leadership -- see [http://www.ecsel.psu.edu/ecsel/](http://www.ecsel.psu.edu/ecsel/)) the course bridges basic principles in engineering and physical science.

The goals of "Fundamental of Science and Engineering Design" ([http://www.ed.psu.edu/ci/scied/scied497F](http://www.ed.psu.edu/ci/scied/scied497F)) are to foster students’ understanding of concepts and principles of physical science and engineering, promote scientific inquiry, problem-solving skills and an appreciation of science and technology. These goals
guided course design and delivery. The description of a sample module provided later in this paper illustrates how the course goals influenced the instruction.

**Course Overview**

A series of three modules provide the structure for this non-majors course. The modules reflect our desire to connect everyday physical phenomena and materials with principles of science and engineering. *Structures, Simple Machines, and Basic Electric Circuits* are the three modules in this semester-long course (see Table 1). This paper describes the *Structures* module as an example of how we designed instructional strategies to meet the course objectives.
**Table 1. - Course Content: Fundamentals of Science and Engineering Design**

<table>
<thead>
<tr>
<th>Module</th>
<th>Content Discussions</th>
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| Module I: Structures    | The stability of various shapes  
The Advantages of Triangles  
Tension and Compression  
Equilibrium  
Truss Analysis  
The Method of Joints |
| Module II: Simple Machines | The Advantages/Disadvantages of a Simple Machine  
Conservation of Energy  
Mechanical Advantage  
Efficiency |
| Module III: Basic Electric Circuits | Conductors and Insulators  
Complete Circuits  
Batteries and Bulbs  
Voltage  
Current  
Resistance  
Series Circuits  
Parallel Circuits |

**Structures: A Sample Module**

The *Structures* module occurs in ten two-hour sessions. We utilize an integrated laboratory and lecture format (sometimes referred to as a "studio" format). The core concepts in this module are stability, tension, compression and equilibrium. For our purposes, we have defined stability as the extent to which a frame structure resists a change in shape.

In keeping with the recommendations of the landmark reports, we employ several strategies to help our students develop conceptual understanding. One such strategy includes assessing students’ pre-conceptions. We do this informally in small and large group discussions and formally using pre-tests featuring multiple choice and extended response formats. We typically use the students’ preconceptions diagnostically to plan
instruction. This planning often entails the design of demonstrations (sometimes referred
to as “discrepant events”) or activities that either raise or lower (in the mind of the
student) the status of their pre-conceptions. The status of a conception pertains to how
plausible, intelligible, and fruitful the student finds the conception (Hewson, 1995).

In the context of the Structures module, we ask students to reflect on the various
shapes of frame structures that they have seen. Further, students decide (all other
characteristics equal) which shape is the most stable. Lastly, students consider alternative
ways to stabilize an unstable frame structure. After discussing these issues in small and/or
large groups, questions are generated for further student investigation. We do not provide
any procedural information for conducting their unstable frame investigations. The
students determine the methods of data collection, analysis, and presentation, assisting
them to develop greater problem-solving and experimental skills. Each group of students
presents the results of their investigation to the instructors and their peers. We believe
that the presentation requirement helps the students to illustrate and communicate
scientific ideas. To facilitate the students’ investigation(s), we provide them with Lego™
pieces that can be arranged in a multitude of ways to form frame structure models (see
Figure 1 for a sample of student work). Students can easily manipulate their Lego™
model to explore its stability (resistance to a change in shape). We chose the Lego™
products because they are simple, inexpensive, and adaptable to many of our curricular
needs. The Lego™ models can be constructed to demonstrate physical science and
engineering principles that would be unobservable using most other materials.
By engaging in activities such as the one described above, students quickly discover the superior stability of the triangular shape, the decreased stability that occurs as an additional member is added to a frame structure, and the benefits of diagonal bracing. Many students, through their exploration of these relationships, have discovered additional properties pertaining to all stable frame structures. For example, in a stable frame structure the number of necessary diagonal braces is always three less than the number of sides in the structure. In addition, the number of triangular regions formed within a stabilized frame structure is always two less than the number of sides in the structure (see Figure 1).

The landmark reports cited above suggest the importance of scientific inquiry skills and problem solving skills. We believe that such skills are best learned when the students design the method in which they investigate and communicate scientific relationships. In short, we have found guided inquiry in the midst of a focused activity to be a powerful instructional strategy.
The students have consistently remarked on the depth of conceptual understanding (of module concepts and inquiry skills) that they have attained as a result of activities structured in this way. In addition, our students tend to be highly motivated to investigate concepts and relationships that they may have seemed counter-intuitive to them in previous discussions.

After the investigations of frame structures, the next step is to apply stability principles to the analysis of simple trusses. Students predict the type of force pairs (tensile and compressive) present in each member of a truss. Again, we encourage our students to struggle with this task alone as well as in small and large groups. Predicting the type of force pairs is a difficult task. Students struggle to visualize tension and compression in the beams since a truss is designed to be static. That is, truss members are rigid, not permitting tension and compression to be observed directly. They typically gain an understanding of tension and compression only after manipulating carefully designed truss models that allow tension and compression to be observed (note string in place of beam in Figure 2).

![Figure 2](image-url)  
**Figure 2.** – A simple truss model constructed of string and Lego™ pieces.
The conceptual development phase of each module typically lasts for six of the ten class sessions. At the end of the conceptual development phase, we introduce the design project for the module. Again, students work in small groups. In the past, the design task for the Structures module was to construct from K-NEX™ pieces a truss bridge that spans a 60 cm channel. This bridge should be the lightest and most inexpensive bridge that will support a 40 N load suspended from its roadway. The students determine the cost of their bridge using an itemized parts list. Students utilize any software that seems appropriate for their design task. West Point Bridge Designer (freeware from the United States Military Academy—http://www.dean.usma.edu/cme/outreach/WPBD/wpbdhome.htm) has proven to be a powerful instructional tool and a meaningful way for students to investigate stability issues within the context of a truss bridge. Our students use this program to simulate the performance of their bridges before load testing in the classroom/laboratory.

The students make a group presentation of the physical science and engineering principles at work in their bridge. In addition, the students are required to describe the process that their group used to arrive at the final design and to relate that process to established engineering design processes. Although the requirements for the design problem are well defined, the processes to solve the problem are determined by the students. Consequently, the students’ designs have been diverse and ingenious (see Figure 3). Recognizing that an engineering problem can be solved in a myriad of ways has been a powerful experience for both the instructors and the students.
At the conclusion of the *Simple Machines* and *Basic Electric Circuits* modules, students revisit their original bridge design and modify it in ways that demonstrate their understanding of the concepts in each subsequent module. This has been a very successful strategy in tying the concepts of the entire course together. For example, at the conclusion of the *Simple Machines* module, the students construct a machine system composed of at least one lever, one pulley, one gear system, and one wheel and axle. This compound machine system must be capable of lifting the bridge constructed in the *Structures* module. The ideal mechanical advantage, efficiency, and cost of the machine system are the evaluation criteria. Finally, in the last module, the students “electrify” their movable bridge by applying basic circuit concepts. Students have approached this task in various ways. Students integrate simple motors into their design to drive the machines that move the bridge. Also, they design and incorporate warning systems. These automated systems typically consist of lights and buzzers to alert drivers once the bridge begins to move.

The modules provide several common experiences for students. These include: conceptual development activities conducted within the confines of guided scientific inquiry, a design project aimed at helping students develop problem-solving skills, and a
design project presentation where students can demonstrate developing scientific inquiry skills such as experimental design, data manipulation, data representation, and the communication of findings.

Closing Remarks

In this article, we described a course designed in response to the recommendations of several landmark reports on the state of physics education. Our emphasis on providing such experiences goes beyond adherence to these recommendations. The non-science majors who take our course are our future community leaders. As community leaders, they may find themselves in positions of control over funding and the allocation of other resources. We believe that the understandings developed in this course can help inform their decisions on science related issues. In addition, many of the non-science majors who take the course are pre-service elementary school teachers. We hope that these future teachers will someday use the skills and enthusiasm developed in this course to “hook” young children on science, mathematics, engineering and technology.
References


