The Importance of Being Explicit when Incorporating Engineering into Science

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Abstract

This in-progress report describes initial findings regarding an experiment to test the effectiveness of curriculum modules that engage students in engineering design practices in the context of high school biology and chemistry courses. Based on pilot studies, the instructional materials have been revised to increase the visibility of engineering design concepts, strengthen the connection between the science concepts and the engineering activities, and emphasize engineering design to a great extent in the professional development of the teachers prior to full field trials of the curriculum models. The final phase of the project is currently underway and results will be reported by the end of 2012.

Introduction

Concern about U.S. competitiveness in the global economy and the development of a workforce with the knowledge and skills to grapple with technical and technological issues has been highlighted on many fronts in recent years (e.g., NAS et al., 2007; NSB, 2007). While increasing the prevalence of engineering in K-12 classrooms may lead some students to careers in technology or engineering fields who would not otherwise have selected this path, there are other reasons for introducing students to engineering at the pre-college level.

Katei et al. (2009) claims that in addition to potentially increasing the pipeline leading to engineering careers, teaching engineering at the K-12 level has additional positive impacts on students ranging from increased student achievement in mathematics and science to improvements in school attendance and retention. One study that supports these claims compared scores on the National Assessment for Educational Progress for students who took courses developed by “Project Lead the Way” (the largest K-12 engineering program in the U.S.) to students in a random, stratified comparison group and found that the students with the engineering course background scored significantly higher in science and mathematics (Bottoms and Anthony, 2005). Overall, however, the evidence to support these claims is weak because there are a relatively small number of studies, and those that exist are of uneven quality and typically small numbers of participants (Katehi, et al., 2009).

One of the major goals of our project has been to add to the body of knowledge related to the impact of incorporating engineering in high school science courses on student learning of science concepts and mastery of 21st century skills. Specifically, we are employing an experimental design with matched pairs of classrooms randomly assigned to either a treatment or control condition. , The experimental treatment consists of a curriculum module in biology or chemistry that includes engineering design activities while the control treatment consists of parallel curriculum modules containing traditional activities. Pre-post achievement tests in biology or chemistry will be used to compare the effectiveness of the experimental and control treatments to teach the science, and a performance assessment administered at the end of each unit will be used to compare the students' abilities to collaborate and communicate.

A second goal of this project is to strengthen the "T" and "E" components of STEM in high school courses taken by a majority of students. Engineering activities at the high school level are most often included in electives or physics classes that relatively few students select. Many more high school students take biology and chemistry courses (particularly biology) than a physics course, and many fewer female students take physics than male students (NCES, 2005). If the teaching of engineering design concepts is confined to electives and physics classes at the high school level, a large percentage of students at this level will not be exposed to these concepts.

The project is currently in its third and final year, midway through implementation in the classrooms of the field test teachers, with collection of student assessment data underway and therefore it is premature to make any conclusions regarding our primary research question. Still, there are perspectives and insights from the development work and observations during the professional development institutes and classroom visits conducted to date that may inform other researchers. We prefer to share our insights sooner rather than later since engineering is expected to be prominent in the Next Generation Science Standards, which is scheduled for release in a few months.

Before presenting our insights we wish to point out that this project was conceived before the National Research Council began its work on *A Framework for K-12 Science Education* (NRC 2012). At the time the idea of including engineering in the high school curriculum was a radical idea. Now it is becoming accepted as the next step in an evolving educational landscape. Since our curriculum modules, student assessments, and professional development institutes were developed three years ago they may not be closely aligned with the NRC Framework. Still, the materials developed for this project and our experiences may provide insight as science education at the K-12 level continues to evolve.

Module Development: Balancing the Perspectives

The biology module is an inclusive package of lessons requiring 3-4 weeks of active participation that engages students in two engineering design activities in addition to traditional classroom and lab activities. The engineering component has students designing, constructing, and testing a small scale algae farm that captures carbon dioxide from a combustion source to enhance the growth of the algae in the farm and which, if constructed at full scale, could moderate the increasing levels of that greenhouse gas in our atmosphere. The two design activities are a component of the algae farm – the device or procedure to collect CO_2 – and the farm itself, a system of sorts. The chemistry module similarly involves two design activities that are related, although not as closely as those in the algae farm. For the purposes of focusing the discussion and limiting the length of the paper, the biology module will be emphasized here.

Having established the content and design activities, attention was focused on the extent to which engineering would be highlighted in the module. The project leadership and advisory board members for our project have a range of backgrounds and expertise spanning various levels of K-12 science education as well as technology and engineering education. Strong and varied opinions were voiced regarding the relative emphasis that engineering should have in the modules and the degree to which it should be assessed. Consideration was also given to the persuasive arguments of classroom teachers voicing the familiar refrain that time constraints prevent them from adding content to their already overloaded district curricula.

Finally, national and state education documents were consulted to provide guidance as to the balance between science content and engineering design that might be justified in the module. While engineering is not a prominent component of the National Science Education Standards (NSES), technology and design both appear there, providing a rationale for teachers and administrators who were interested in engaging students in non-routine problem solving. The module also addresses significant life science content as shown in Figure 1 below.

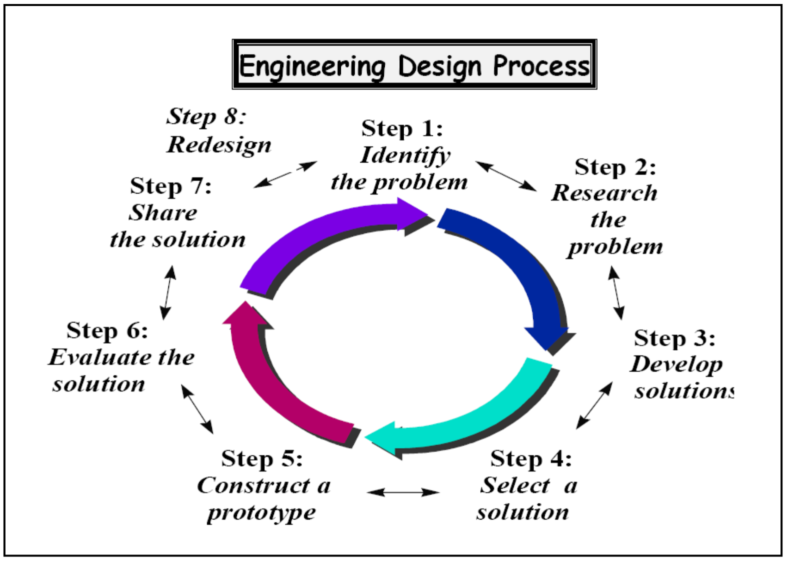
Figure 1: NSES addressed in the algae farm module*

- Content Standard A: Science as Inquiry
- Content Standard C: Life Science
    - Interdependence of organisms
    - Matter, Energy, and Organization in Living Systems
- Content Standard E: Science and Technology
    - Abilities of technological design
    - Understandings about science and technology
- Content Standard F: Science in Personal and Social Perspectives
    - Natural and human-induced hazards
    - Science and technology in local, national, and global challenges

*Aspects of each of the listed standards are addressed, not entire standards

After weighing the input from the various stakeholders, the decision for the pilot test year was to emphasize the engineering design process in the module and the professional development (PD) institute but to include a limited number of related engineering concepts, such as constraints and optimization and not to emphasize them or to assess student understanding of engineering. The first iteration of the module that was used for PD and in the classroom introduced teachers and students to the design challenges in the PD sessions or in the classroom. Following this introduction and a general sense that teachers and students alike of being overwhelmed by the prospect of developing a solution to the problem that was presented, they were exposed to design processes in a variety of ways (see Figure 2 for the schematic diagram employed in this project) and were asked to compare the processes of engineering design and scientific investigation. They were advised that they would use an engineering design process to solve the problem that had been posed.

Figure 2: Diagram of EDP used in the modules



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Teachers and students alike were actively engaged in developing the best solution possible given the constraints of the design project. Observations in both the PD sessions and classrooms during the pilot test of the modules, however, raised some concerns about the level of understanding of engineering practices and the degree to which the design activities reinforced the science concepts, a major objective of the project.

Observations and Revision: Increased Emphasis on Engineering and Making Connections

The initial version of the curriculum module provided all of the handouts and instructions for a variety of activities including data analysis, labs (both wet labs and virtual labs), and engineering design activities. Instructions were provided for both teachers and students and background information in several areas, particularly related to engineering was provided for teachers. Additionally, some suggestions for engaging students in classroom discussions were provided. Given this set of materials, the PD sessions were led in a manner that was intended to model how the activities would be conducted in the classroom.

Observations in the classrooms of the teachers who were implementing the design activities, however, raised concerns regarding their understanding of engineering design or their ability to facilitate these activities in the classroom. The activities were being implemented and both teachers and students seemed generally engaged and pleased with the outcome, but in many cases, the observed activities often fell somewhat short of what we would expect from an engineering design activity. The primary observation that illustrates our concern deals with the students' approach to solving the problem. Most groups took a trial-and-error approach even when the content of prior lessons had provided them with background knowledge that would inform their decisions in the design problem. In some cases, students and teachers were comfortable with the approach being taken because it seemed scientific. As one chemistry student said: “We’re going to make all the possible combinations of chemicals, see what works, and then look at the safety and cost for those chemicals that work to decide what is the best solution.” This approach was also made possible within the time constraints because the teacher had prepared all of the solutions in advance, rather than requiring students to determine which solutions to use, the concentration to be used, and to prepare the chemical solutions needed to test their design solution. In other words, by trying to be helpful and complete the project within time constraints, some of the engineering decision-making was left out of the lesson.

A second concern arose and was reinforced during observations and discussions with students engaged in the design activities. This concern involves the connection, or lack thereof, between either the design activity and the science concepts or the model being constructed and what it represents. Students were intent on achieving the goals of the design activity but they seemed to approach this as an isolated challenge rather than one that was connected to science concepts that they were learning or the real-world application that was being modeled.

Based on our classroom observations and discussions with teachers, we concluded that we needed to be more explicit in the materials we provide to both teachers and students and in the PD experience. This involved revising the curriculum module and modifying the PD experience. We recruited teachers from the pilot study to work with us to revise the modules during the early summer following their implementation. Some of the revisions included the following:

- Increasing the visibility of engineering concepts, including design, in the modules.
    - For example, biology students were given the description of another design challenge and two proposed solutions to the challenge. They are now required to apply knowledge of engineering concepts by identifying pertinent engineering pieces in the sample, such as constraints, trade-offs, and modifications they would make if they were to redesign one of the systems.
    - Engaging students in predictive analysis, but using a spreadsheet so the level of the mathematics is not an impediment
    - Increasing student involvement in decision-making related to the design activity by providing data sets that should inform their design decisions
- Making more explicit connections between the other module activities and the design challenge.
    - Students construct a “learning road map” which indicates concepts and skills they have identified as needed to complete the design challenge. They periodically review the learning road map to summarize what they have learned that applies to the challenge.
    - When the design challenge is introduced early and followed by activities that are related to it over an extended period of time, highlighted questions are posed within the activity that explicitly link it to the design challenge.
- A greater emphasis was placed on engineering design in the PD sessions for the field test teachers.

- Explicit comparisons were made between design challenge activities and science investigations and how to distinguish between them.

Another modification that we made involved revision of the assessment. The field test version of the assessments does include items intended to measure student understanding of engineering design and related concepts. Although our original proposal did not include this aspect and science teachers in general are not (yet) interested in their students' understanding of engineering, we feel that it is important to measure this for a variety of reasons. One reason is that our hypothesis regarding student learning is based on the incorporation of engineering design activities, so it is important for us to know whether the engineering aspect was a contributing factor in facilitating that learning. On a broader level, there is potential for this project to contribute to the knowledge base with respect to an engineering learning progression at the K-12 level. The assessment data for this construct will be insufficient to report major findings, but they may be informative in this area.

Discussion

Like the pilot test teachers, the field test teachers are all implementing the modules for the first time during the current academic year. We would like to report that the design challenges look like engineering design activities in all classrooms and that student learning has increased markedly. However, while that is not the case, there have been some tremendous successes along with a few dismal showings, and a great many in the middle that represent teachers who have made significant strides but are struggling with implementation.

The current version of the modules, with more explicit instruction regarding engineering concepts and guidance for implementing these activities in the classroom, were an improvement over the initial versions based on classroom observations and informal discussions with teachers. Nonetheless additional revisions are likely for two significant reasons. First, student assessment data and teacher survey data are in the process of being collected and will be analyzed within the next several months. These data are summative in nature as the project is in its final year of funding, but the data should also be considered formative – it will be used to inform the revision of the modules before they are distributed on a wider scale.

Second, the Next Generation Science Standards will be released within the next several weeks and, based on the Framework document for those standards, engineering design and related concepts will have a home within the K-12 science classroom. This standards document will also shape the next iteration of the modules as it will outline engineering concepts and performance expectations for K-12 students. Adjustments will be made in the language of the module and the expectations to reflect the most current thinking regarding the inclusion of engineering in the science classroom.

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