# Engineering Our Future New Jersey:

## Evaluation of a High School Pilot Project

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## Executive Summary

### Overview

Engineering Our Future New Jersey (EOFNJ) is a collaborative effort among several partners to bring exemplary technology and pre-college engineering curricula to mainstream New Jersey K-12 education. Led by the Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology, the goal of the Engineering Our Future New Jersey initiative is to ensure that all K-12 students in New Jersey experience grade-appropriate engineering curricula with a focus on innovation. CIESE launched a pilot study in spring 2006, which engaged 35 teachers from 32 ethnically, socio-economically, and geographically diverse elementary, middle and high schools throughout New Jersey.

This evaluation study concerned the high school portion of the pilot, which involved 498 students from 17 classrooms (average class size of 29 students), spanning grades 9-12. The eleven teachers involved in the pilot had various teaching assignments including physics, physical science, conceptual physics, honors physics, AP physics, technology, and pre-engineering. All teachers were provided with instructional materials and attended a two-day professional development program on a new curriculum that had been developed by the National Center for Technological Literacy at the Museum of Science in Boston, called *Engineering the Future: Designing the World of the 21$^{st}$ Century*.

*Engineering the Future* (EtF) is a full-year introductory engineering course designed to provide a firm foundation in physics while increasing the technological literacy of all students. A central goal of the course is to develop students' practical understanding of how we are all influenced by technology and how we all influence future technological development by the choices we make as workers, consumers, and citizens. In order to align with the science education standards of the state of New Jersey, instruction included just the second semester of the curriculum, which included the application of concepts in thermal/fluid systems and current electricity to engineering design projects.

This study was designed to evaluate the effectiveness of the program in improving the students' abilities to understand and apply the key concepts presented in the curriculum. A comparison of pre-tests and post-tests indicated that the *Engineering the Future* curriculum significantly improves high school students' understanding of these important concepts and skills. A detailed item analysis was also conducted to better understand the students' needs, to pinpoint areas in which the curriculum and/or professional development might be improved, and to identify promising teaching strategies. Following is a summary of the study and its key findings.

**The Study**

Prior to the start of the pilot study, research staff at CIESE reviewed the *Engineering the Future* curriculum to align the materials with New Jersey Core Curriculum Content Standards. The following two units were selected and adapted for implementation from the total four units in the full-year EtF curriculum:

**(1) Project 3: Fluid and Thermal Systems—**Students investigate the topics of thermodynamics, energy transfer, fluid mechanics, work and motion as they construct a putt-putt boat that runs using a fluid/thermal engine. Their challenge is to first understand how the engine works and then to re-design one aspect of the boat in order to improve its design. Students show what they've learned by preparing patent applications to protect their creative ideas.

**(2) Project 4: Electrical and Communication Systems—**Students work with Snap Circuits, an electronics kit in which components can be quickly and easily snapped together. Using switches, motors, speakers, resistors, light bulbs, and LEDs, students explore how electricity flows through different circuit arrangements and apply their understanding to a series of small design projects, including a rodent alarm and a multi-speed fan. Project 4 concludes with an exploration of electronic circuits useful for communication.

The high school pilot study began with a two-day professional development workshop conducted at Stevens Institute of Technology by staff from the Museum of Science, Boston and CIESE on December 1 and 2, 2005. The workshop included an overview of the pilot program and the EtF curriculum. Through a series of short lectures and hands-on activities the teachers gained experience in implementing the selected units and teaching the desired concepts and skills.

The teachers then implemented the two units between January and June, 2006. Two to three weeks were allotted for each of the two units. The CIESE staff visited each of the school sites at least twice, where they assisted pilot teachers with the scheduling and implementation of the curriculum, and observed the EtF classes in progress.

The pilot teachers were responsible for completing surveys regarding the implementation of the materials, administering pre- and post-tests just before and after finishing each of the units, and participating in a focus group in June 2006 to discuss their experience of working with the curriculum. The CIESE staff scored the pre-post tests, based on assessment instruments created by the EtF developers in Boston.

All participating pilot teachers received a stipend for participating in the professional development program, as well as enough equipment and materials to implement the curriculum without any additional cost to the schools.

All of the tests were scored by the CIESE staff, and the resulting data were provided to the NCTL for analysis. Following is a summary of key findings.

**Key Findings**

The data analysis was based on the total number of students for whom we have the results of both pre- and post-tests. For Project 3 this number was 278 students. For Project 4 the number of students varied as described on p. 11. The results show that the *Engineering the Future* curriculum significantly improved students' ability to apply concepts of fluid/thermal systems and electricity to engineering projects. The determination of significance for all of the analyses were based on Pearson's chi-square tests. If $p<.05$ we can be confident that the observed difference was not due to chance. Specific findings and supporting evidence are summarized below.

**(1) Students significantly improved their ability to answer questions about fluid/ thermal systems.**

For Project 3, there were seven questions included in both pre and post tests, which were designed to assess students' understanding of fluid and thermal systems. The average percentage of correct answers to questions about fluid and thermal systems increased significantly from the pre-test 42.52% to the post-test 60.47% ($p< .000$).

**(2) Students significantly improved their ability to answer questions about electric circuits.**

For Project 4, there were sixteen questions concerning simple circuits, series and parallel circuits, electric power and energy. The average percentage of correct answers to questions about electric circuits increased significantly from 52.65% to 65.7% from pre to post test ($p< .000$).

**(3) Students significantly improved their ability to explain phenomena in electric circuits**

For most of the questions in Project 4, students were also asked to explain their answers. These explanations were scored separately to determine if students were applying the correct model of electricity, not simply giving the right answer by chance. The average percentage of students who correctly explained different phenomena in various types of electric circuits increased significantly from 11.99% to 32.91% from the pre-test to the post-test ($p< .000$) indicating improvement not only in understanding how circuits function, but also in their mental models of electrical phenomena.

**(4) Students significantly improved their level of confidence in understanding electric circuits.**

Many of the questions in Project 4 also asked students about their confidence level when confronted with questions about electric circuits. The percentage of students who reported a high confidence level[1] significantly increases from 34.25% to 53.85% from the pre-test to the post-test ($p< .000$). This finding suggests that the *Engineering the Future* curriculum successfully enhances students' confidence in understanding electric circuits.

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[1] I regrouped the confidence level as (A) No confidence, which refers to students who circled "Blind guess" in pre and post tests (B) Medium confidence, which refers to students who circled "Not very confident " or "Somewhat confident," and (C) High confidence, which refers to students who circled "Confident" or "I'm sure I'm right."

**Insights and Recommendations**

The pre-test findings revealed that many students already possess some understanding of the content before instruction, which may result from life experience and/or prior instruction. However, many students also begin the course with fundamental misconceptions that may prevent them from correctly predicting what will occur in a specific situation, or more often, explaining how or why a phenomenon occurs. Since these misconceptions tend to be deep-seated mental models about the physical world, the challenge for the teacher is not simply to introduce new material, but to help their students replace their misconceptions with a more productive understanding of the phenomena.

Our item analysis supports the findings of previous studies that many students have misconceptions about electricity, and that most of these erroneous ideas can be classified as one of a small number of common misconceptions, or incorrect mental models about electricity (Shipstone, 1985; Koumaras *et al*., 1997; Asami *et al.*, 2000). This finding can be very helpful to teachers since they will be able to anticipate the pitfalls that their students may encounter and devise different strategies for different misconceptions. These erroneous ideas are described in detail in the item analysis on the following pages. They have also been taken into account in the next iteration of the EtF curriculum.

These findings also suggest a general teaching strategy: to begin each new topic by encouraging students to discuss their initial thoughts about what would happen in a particular case and why. For example, before studying simple circuits, a class of students might be shown an electrical circuit and asked to explain whether a bulb will light or not. As suggested by previous investigators (Koumaras *et al*, 1997; Trumper, 1997), such discussions would be helpful for teachers to identify any misconceptions that need to be replaced, and would help students become consciously aware of their current thinking, which is an important first step in the learning process. Subsequent instruction should help students test their initial models in situations where they can gradually replace any misconceptions with a more productive scientific understanding.

In conclusion, we wish to emphasize that the post-test findings indicate that many students were successful in changing their mental models during the course, in some cases dramatically. However, the data reported above indicate that there is room for improvement, as we would like to see the percentage of correctness in each post-test question to be much closer to 100%.

The next section of this paper reports on the item analysis, which discusses the results of all questions and students' common misconceptions in detail.