Engineering is Elementary: A Summary of the National Evaluation of Years 2-3

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Engineering is Elementary

Engineering is Elementary (EiE) is a curriculum designed to teach elementary students about concepts in engineering and technology. The curriculum consists of individual units that are intended to supplement the teaching of specific science topics. Each unit is organized around a particular field of engineering and the design of a technology. Each unit begins with a story about a child who solves a problem using the engineering design process, setting the context for the remainder of the unit. Additional lessons follow that encourage students to investigate and test materials and processes themselves for their designs, which culminates in a final design challenge.

Ten of twenty planned units have been distributed throughout the United States so far and we have pre- and post-assessment data from students field testing these units in California, Colorado, Florida, Minnesota, Massachusetts, and New Jersey. We also have control data from one district in Massachusetts, where EiE was not implemented during the 2005-2006 school year, and control data from classrooms that were implementing EiE but completing unrelated units. We used data from all of the EiE field sites and both control samples for this report.

Evaluation of 2005-2006

This report summarizes findings from our evaluation of the six EiE units we tested nationally in 2005-2006: *Designing Water Filters*, *Designing Walls, Designing Bridges, Designing Windmills, Making Work Easier*, *and Designing Hand Pollinators*. The goal of our evaluation was to (1) learn more about what students on a national level know about engineering, technology, and the engineering design process and (2) evaluate the effect of the *Engineering is Elementary* curriculum on students' understanding of engineering, technology, and related science topics.

Pre- and post-assessments were collected for each unit[1] for both the EiE (test) students and control students. EiE students received one of several assessments on general engineering and/or technology topics and other assessments specific to the unit they studied. Control students received a variety of questions from different unit assessments and from the general engineering and technology assessments.

Sample

The EiE sample is 5,139 students and the control sample is 1,827 students. Whenever possible, EiE student responses were compared to control student responses. Neither grade nor gender differences between samples were statistically significant though significant differences did exist in the areas of racial makeup, the proportion of students receiving free or reduced lunch and students classified as Limited English Proficient (LEP)[2].

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[1] When possible, pre-assessments were given in October or November, and post-assessments in May or June of the same school year. Due to varying circumstances of individual teachers, at times pre-assessments were given later and/or post-assessments earlier.

[2] The control sample has a significantly higher proportion of students receiving free or reduced lunch and proportion of students classified as Limited English Proficient (LEP). The control sample also has proportionally more White students while the EiE sample has more Black, Asian and Hispanic students.

As well, due to challenges getting assessments back from teachers the number of students who completed each type of assessment and the distribution across grades varied widely. We also expected teachers to complete related science instruction with the EiE unit, however, post-unit feedback indicates that many teachers did not complete related science instruction, while others completed related science instruction long before they began the EiE unit or administered its pre-assessment. We are not certain whether and to what extent concurrent science instruction impacts performance on the assessments so current sampling methods (to be reported in the future) match the grade of students and the science taught more closely.

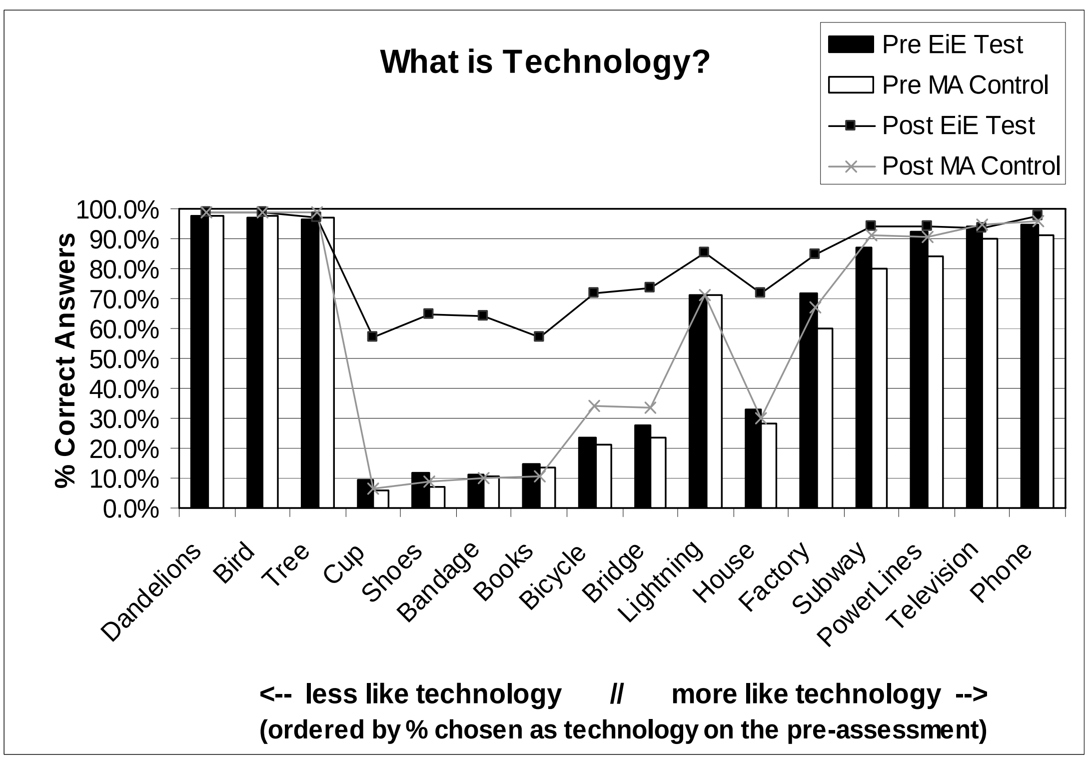
Results for General Engineering Assessments

EiE students were tested before the unit was begun and after it was completed, which allows for a test-retest analysis. Each classroom of students answered a different subset of *General Engineering* questions, in order to avoid assessment fatigue, so an overall "general engineering & technology" score for each student is not possible.

What is Technology?

The *What is Technology?* assessment asks students to choose which items are technology from 16 possible items.[3] Figure 1 displays the percentage of correct pre-and-post responses for each item for both the EiE and control samples. Statistically significant p-scores are marked in bold. The items are ordered in the table based on which were least and most likely to be considered technology by the EiE students on their pre-assessments. This ordering is robust across gender, state and racial/ethnic differences. Previous research indicates that students tend to consider (1) anything powered by electricity or (2) anything new or modern to be technology and findings from this study are consistent [1, 2].

Figure 1



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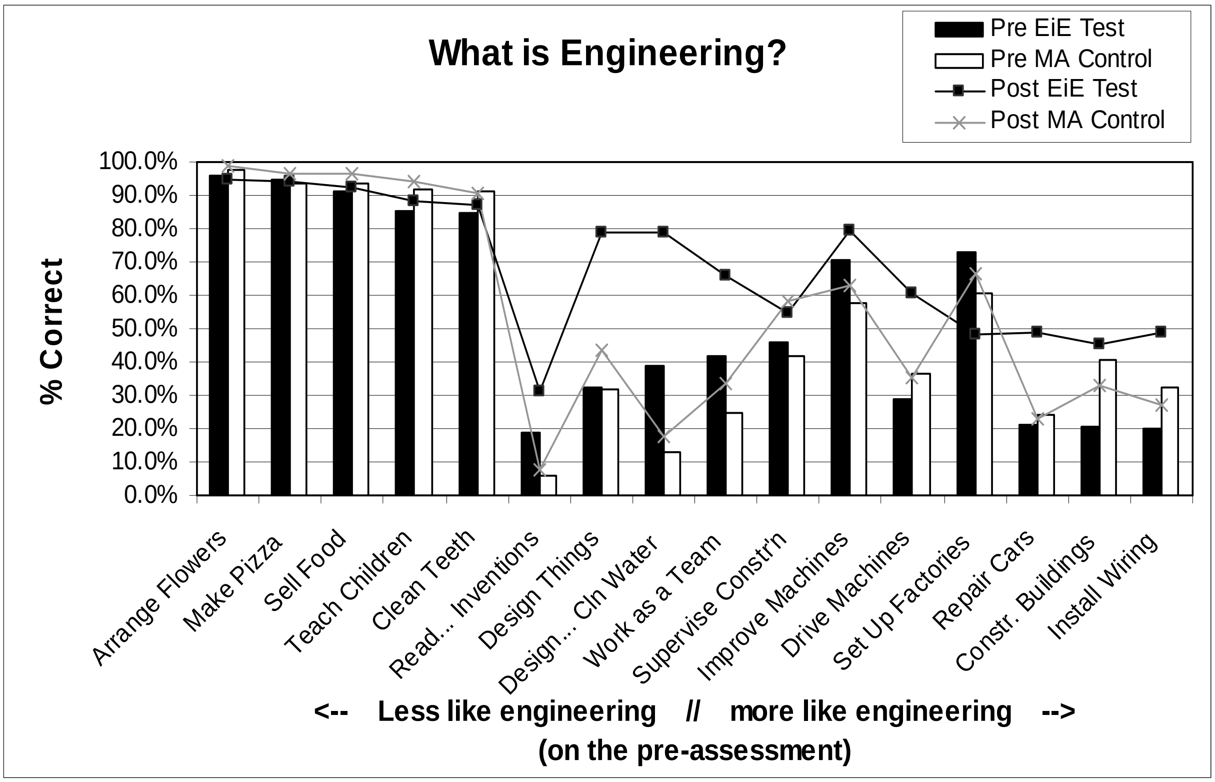
[3] EiE considers the human-made world to be technology, following the definitions from prominent proponents of engineering and technology education: the International Technology Education Association (ITEA) [3] and the American Association for the Advancement of Science (AAAS) [4].

EiE students improved significantly more than control students on their post-assessments and EiE improvements were greatest on the items they were least likely to call technology on the pre-assessment. As well, EiE students were much more likely to answer that technology is anything "human-made" on the post-assessment open-ended question.

What is Engineering?

The *What is Engineering?* assessment asks students to choose which items are engineering from 16 types of work engineers might do.[4] Two versions of this assessment were used during this study, which included some varying distracters.

Figure 2



EiE students showed significant pre-to-post improvement on 15 of the 22 items tested from both versions of the assessment. Statistically significant p-scores are marked in bold for each sample in Figure 2. For 14 items, EiE improvement was dramatic (between 8-46% overall) and significant (p<.000). On three of the items for which control data is available, the control sample also improved, however, improvement was 15-35% less than EiE improvement.

Vocabulary

The *Vocabulary Assessment* asks students to complete sentences by choosing the appropriate engineering vocabulary word from a list of six possible choices. Both samples performed significantly better on the post-assessment for all vocabulary words, however, EiE particularly improved on three items: technology, design, and engineer.

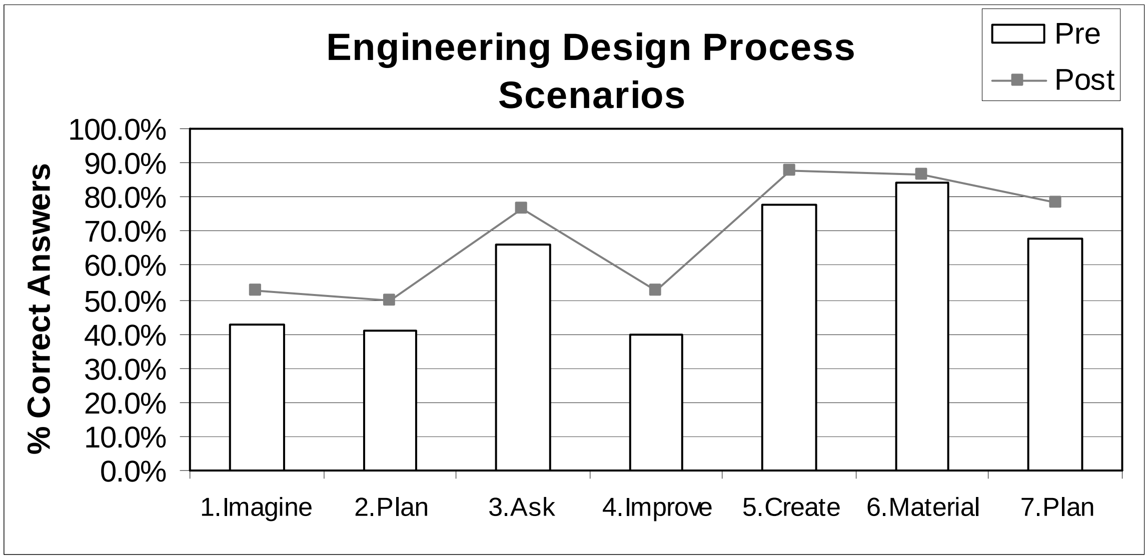
[4] EiE scores this assessment according to the International Technology Education Association definition of engineer: "A person who is trained in and uses technological and scientific knowledge to solve practical problems" (page 238)… [E]ngineers "are the innovators and designers" (page 23). [3]

A newer version of this assessment, which uses the same fill-in-the-blank sentences with three multiple-choice options for each sentence, was tested with a portion of the EiE sample and appears to be more difficult for students. However, EiE students improved much more dramatically from pre-to-post on this version than the original.

Engineering Design Process

On this assessment EiE students were asked questions about the engineering design process that presented scenarios in which children were designing something. Students were asked to determine what step of the engineering design process the child was engaged in or would be engaged in next. On all questions but one, EiE students were significantly more likely to choose the correct answers on the post-assessment than on the pre-assessment as Figure 3 illustrates.

Figure 3: Engineering Design Process Assessment



Gender

Male students tended to do better on the *What is Technology?* Assessment, while performance of male and female students was more equal on *What is Engineering?*. Female students performed slightly better than males on the *Vocabulary* assessment, and much better on the *Engineering Design Process* assessment.

Race/Ethnicity

White and Asian students tended to perform better than Black and Latino students on *What is Technology?* and *What is Engineering?*, however these differences have not been measured for significance between races/ethnicities because the sample sizes are so widely variable.

Results for Unit Assessments

The following section summarizes results from the six EiE units we tested nationally in 2005-2006.

Designing Water Filters

Students participating in the *Designing Water Filters* unit learn about environmental engineering and the design of water filters. The corresponding pre- and post-assessments asked questions about water filters, water filter materials, and environmental engineering as well as science questions about water.

EiE students performed better than control on one of three questions where control comparison was available. EiE students improved significantly from pre-to-post testing on the majority of both the engineering and science questions.[5] There were few significant differences between male and female students on this assessment, with females showing slightly better performance in most cases where there were differences. As well, while White and Asian students performed better than Black and Latino students, it is unclear whether this is more due to regional differences or racial differences.

Designing Walls

The *Designing Walls* unit examines the design of mortar for use in building walls and students learn about the properties of materials, how those properties affect how materials can be used in designs, how to test different kinds of earth materials and how to construct and test sample walls using mortar they design. On the corresponding assessment, students were asked questions about the properties and application of earth materials and the composition of soil.

Both EiE and control students improved from pre-to-post testing; EiE students improved somewhat more than control students on all of the assessment questions. Male students did better on the post-assessment than females for one of three questions, but otherwise performance was statistically the same.

Designing Bridges

The *Designing Bridges* unit teaches students about civil engineering and the design of bridges. Students identify push and pull as two kinds of force, test three varieties of paper bridges for structural strength and then design their own bridges from paper, string, and other simple materials. The assessment asks students a variety of questions about bridges, structural strength, and structural stability.

EiE students improved significantly and often dramatically from pre-to-post testing on all of the assessment questions for this unit but one[6]. Male and female student results were statistically the same.

Designing Windmills

Students participating in the *Designing Windmills* unit learn about mechanical engineering and the design of windmills and wind turbines. Students examine various machines, their moving parts, and how the machines transform the direction of force. Students design sails for a “boat”, and design small windmills that can lift weights (do work).

On the pre- and post-assessments for this unit students were asked a variety of questions about windmill design, wind energy, technologies using the wind, and mechanical engineering. EiE students performed significantly better on the post-assessment than they did on the pre-assessment on 12 of 15 questions. However, on questions for which a control sample was available, EiE students performed no better than the control sample, which was drawn from students who completed at least one EiE unit which was not the windmills unit. Male and female performance on the assessment questions was roughly equivalent.

Making Work Easier

The *Making Work Easier* unit focuses on industrial engineering and the design of factory subsystems using simple machines. Students learn about processes as a form of technology, test different simple machines, and design and improve “factory subsystems” to move potatoes from one place in the classroom to another.

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[5] While a control sample was used for four questions on this assessment, our analysis questions the suitability of test-control comparison and further control testing is needed.

[6] The control sample for *Designing Bridges* was too small to be used for statistical analysis; reporting is done for EiE only.

The unit's corresponding assessment asked students to: identify simple machines, processes, and technologies, improve assembly lines, and answer questions regarding the application of force in different situations when using simple machines. EiE students improved significantly from pre-to-post testing on most of the assessment questions (15 of 21) and improved somewhat, but not dramatically, more than the control comparison group on the post-assessment. Males performed better than females on both the pre-assessments and the post-assessments, but females made greater gains on the assessments.

Designing Hand Pollinators
The *Designing Hand Pollinators* unit primarily focuses on agricultural engineering, natural and technological systems, and connections to pollinating and pest insects. Students learn about Integrated Pest Management as a method for managing, rather than eradicating, the natural system of predator and pest insects within human agriculture, given the damage pesticides and eradication can cause to the whole ecosystem. Students test different materials' ability to pick up pollen and design hand pollinator models for different (modeled) shapes of flowers.

EiE students improved significantly on almost all assessment questions for this unit. As well, EiE students tended to do at least slightly and sometimes much better than control students, when comparable test-control data was available.[7] Differences between male and female students were minor or nonexistent on these assessments.

Race/Ethnicity

Our analysis indicates that race/ethnicity is strongly correlated with region and that each region in our sample has its own standards for science as well as its own methods for teaching science, engineering, and technology. As well, there are limitations on the significance test for multiple non-parametric categories so further analysis will be necessary to determine the variables that are relevant to differences in performance across racial/ethnic groups.

Conclusion

Overall, Engineering is Elementary students consistently demonstrated improvement on post-assessments designed to assess student understanding of science and engineering concepts. Where comparison to a control sample was available, EiE students, for the most part, performed significantly better than control students, indicating that EiE students demonstrate:

- A clearer understanding of technology as human-made.
- A clearer understanding of engineering careers and that engineering involves design and teamwork.
- A better grasp of relevant engineering and technology vocabulary.
- A clearer understanding of the engineering design process.
- A clearer understanding of materials, their properties, and their uses in engineering design scenarios.
- An increased likelihood understanding of related science content.
- A clearer understanding of how to improve technologies.
- A clearer understanding of what a process is and how it is a type of technology.
- A clearer understanding of the criteria for judging the effectiveness of a technology.

While it could be argued that learning about the properties of materials discussed in the EiE units, such as water filters or hand pollinators, is not an essential component of a child's education, we espouse that it is

[7]The control sample is more heavily weighted towards older students than the test sample, so comparison was not always appropriate.

through these specifics, which involve fun, educational activities, that students learn the broad, basic lessons of engineering, technology, and engineering design. As well, we aim to introduce students to the basic concepts of the applied sciences[8] while giving them a taste of the enormous variety of technologies and designs that engineers work on. The findings from our 2005-2006 research presented here provide strong evidence that we are indeed meeting these goals.

Next Steps

We are currently collecting data for new units and collecting updated control data using the revised assessment questions mentioned throughout this report. We are more closely matching test and control populations to enable a more complete and robust comparison analysis and plan to more deeply explore the relationship between EiE performance and gender, socioeconomic status, and English proficiency. As well, we plan to explore the relationship between student learning of science content in classrooms where EiE is integrated and where science is taught without engineering.

Bibliography

[1] C. M. Cunningham, C. Lachapelle, and A. Lindgren-Streicher, "Assessing elementary school students' conceptions of engineering and technology," presented at American Society of Engineering Education, Portland, OR, 2005.

[2] C. M. Cunningham, C. P. Lachapelle, and A. Lindgren-Streicher, "Elementary Teachers' Understandings of Engineering and Technology," presented at American Society for Engineering Education Annual Conference & Exposition, Chicago, IL, 2006.

[3] International Technology Education Association, *Standards for technological literacy: Content for the study of technology*. Reston, VA: ITEA, 2000.

[4] American Association for the Advancement of Science, *Science for all Americans*. Washington, D.C.: American Association for the Advancement of Science, 1989.

[8] Objects and processes can be categorized as natural or human-made; human-made objects and processes can be described as technologies; the engineering design process is a principled process that is different from and similar to the process of scientific discovery; familiarity with materials and their properties is an important prerequisite of engineering design; engineering is a profession that requires skill, creativity, and knowledge of science and mathematics; novices can begin to practice engineering, just as they can practice scientific inquiry at an amateur level in an intellectually honest way; engineering design can be fun, can help people, and is worth learning to do better, technology and its design has enormous impact on people, societies, and the earth.