Research and Evaluation Results for the Engineering is Elementary Project, 2004-2014

An Executive Summary

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An Executive Summary

Engineering is Elementary (EiE) is a research-based program that incorporates research, evaluation, and assessment into all aspects of curriculum design and testing. A pioneer in the field of engineering for elementary students, the EiE project continues to evolve and refine research questions, assessment instruments, and research methods as the project grows and matures. Our funding partnership with the National Science Foundation (NSF) challenged us to use a rigorous process to develop a curriculum program that could serve diverse student learners in school settings around the country. This document summarizes some of the most notable findings from the project's first ten years, drawing on studies conducted by both project staff and external evaluators. The findings from most of these initial studies merit larger-scale, follow-up studies. The reports and papers cited here can be found in full-text format on our website: http://www.eie.org/engineering-elementary/eie-research.

Conceptions of Engineering

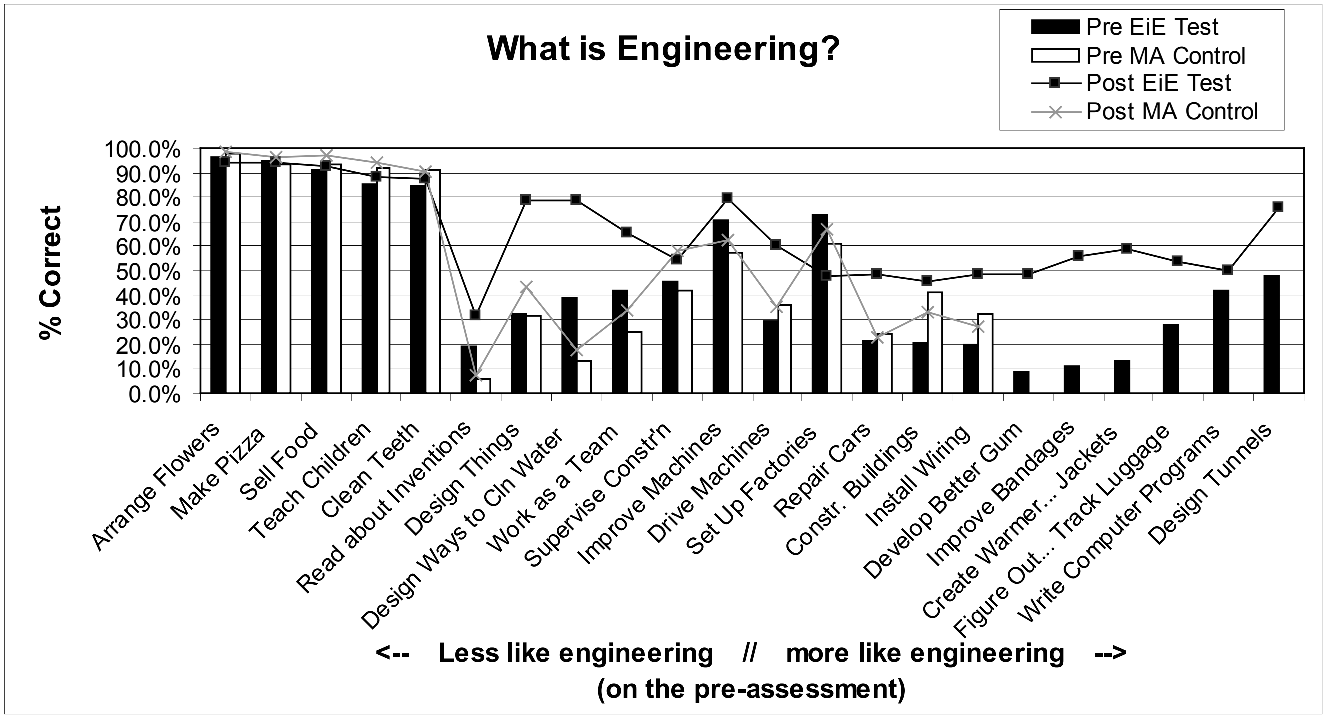
Student Conceptions: *How do children aged 6 – 11 describe engineering and what engineers do?*

An instrument called the Draw an Engineer Test probes children's conceptions of engineering, asking them to explain what engineering is, to draw an engineer at work, and to describe their picture in words. The results suggest that students have limited understandings of the type of work engineers do. Drawings focus heavily on constructing roads, buildings, or bridges; fixing cars; using or fixing computers; and driving trains. Students' awareness of the range of fields that engineering encompasses is fairly limited, and student responses focus heavily on structures (construction workers: civil engineering), cars/machinery (auto mechanic: mechanical engineering), and computers (computer technician: computer/electrical engineering) (Knight & Cunningham, 2004).

To more systematically probe children's conceptions of engineering, the EiE team developed the "What is Engineering?" instrument. It included captioned images of people working and asked students to choose those tasks an engineer would do at work. Students were also asked to respond to the open-ended question "What is an engineer?" Over 7,000 students completed a pre- and post- test of the validated instrument. Findings revealed similar patterns in students from all regions and all ethnic groups. Students tended to focus on the descriptor noun and not the verb and were most likely to identify tasks involving construction or machines as engineering, such as "install wiring," "construct buildings," or "repair cars." They were least likely to identify as engineering tasks from non-mechanical/civil engineering fields, for example "design ways to clean water," (environmental engineering), "develop better bubble gum," (chemical engineering) and "figure out ways to track luggage" (industrial engineering) (Christine M. Cunningham, Lachapelle, & Lindgren-Streicher, 2005).

The EiE team used pre- and post-assessments to compare students who had participated in an EiE unit with a control sample of students in Massachusetts who did not use the EiE materials, and found that EiE students show dramatic and significant change in their understanding of the kinds of work that engineers do. Post-testing of EiE students indicates they are significantly more likely to identify engineering items relating to the design of all types of technology, and are less likely to choose non-design items relating to construction or repair work (see Figure 1) (Christine M. Cunningham et al., 2005; Lachapelle & Cunningham, 2007).

Figure 1: Elementary Students' Conceptions of Engineering



We have further refined the "What is Engineering?" instrument, including adding questions about what types of activities are important to the work of engineers, constructing scales based on the conceptions of engineering that have been observed in previous studies, and validating the instrument. Over 1,000 Minnesota students in third and fourth grade who had not yet started EiE were assessed using the most recent version of the instrument, then compared with a sample of professional engineers. Use of the "What is Engineering?" instrument confirmed that students' naive conceptions of engineering focus on working with electronics, repairing or installing things related to cars, and constructing large building projects using tools, and not tasks like non-electronic design (for example "develop better bubble gum"). Once again, students are focusing on the subject of the work, not the type of work being done. In comparison, professional engineers have very clear ideas about what is and is not engineering based on whether or not the work involves designing and inventing, not what is being designed (Lachapelle, Phadnis, Hertel, & Cunningham, 2012).

In a more recent study, 731 Minnesota third, fourth, and fifth grade students completed the instrument prior to and after experiencing an EiE unit. For most demographic groups, these students' scores on the whole instrument increased significantly from pre- to post-test (Lachapelle, Hertel, Shams, & Cunningham, 2013). We are currently using Structural Equation Modeling analysis to further refine the "What is Engineering?" instrument and explore students' conceptions of engineering before and after engaging in engineering education.

Teacher Conceptions: *How do elementary teachers describe engineering and what engineers do?*

The "What is Engineering?" instrument was also administered to 100 teachers. Teachers' responses followed a pattern similar to students' responses, although they were more likely on all items to correctly discriminate between engineering types of work and non-engineering work (C. M. Cunningham & Lachapelle, 2007).

Conceptions of Technology

Student Conceptions: *What do students think technology is?*

A "What is Technology?" instrument that asked children to choose which captioned items were technologies was also developed by the EiE team and administered to nearly 7,000 students in grades 2–5 across the country. In general, children identify technology with items that run on electricity and power (Christine M. Cunningham et al. 2005; Lachapelle & Cunningham, 2007) and are unlikely to view items such as bandages, cups, or shoes as technology. These results are robust when compared by region or gender, though males are slightly more likely than females to have a broader conception of technology (Lachapelle & Cunningham, 2007).

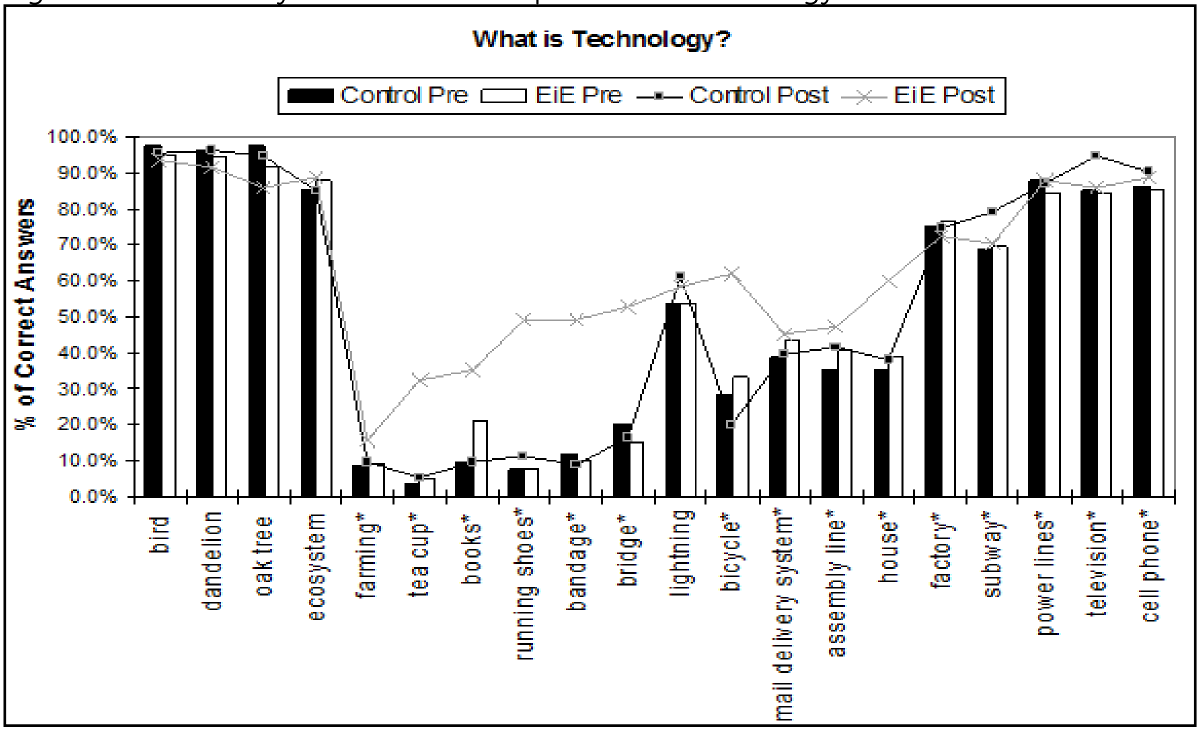
Experience with the EiE curriculum dramatically and significantly broadens students' understanding of technology. We compared pre- and post-assessments of a national sample of students engaged with EiE materials to a control group in Massachusetts that did not use EiE. After completing an EiE unit, students are significantly more likely to indicate that commonplace, human-made items are technology (Lachapelle & Cunningham, 2007).

A more recent analysis of a newer version of the "What is Technology?" instrument looked at data collected from 2006-2009 from 1,092 students in grades 3-6. This sample included both EiE and control classrooms (57% and 43% of the sample, respectively) from multiple states including Colorado, California, Minnesota, and Massachusetts. Using the backward stepwise method of regression, a significant model emerged ($p<.001$), explaining 41% of the variance and showing a large Cohen's d effect size (0.804) of the treatment on the post-assessment after taking into account pre-assessment scores. Though demographic variables also affected scores, these effects were consistent across both control and treatment groups. Student choices on the post-assessment were examined using Principal Components Analysis (PCA). PCA is a data reduction technique that derives linearly uncorrelated variables, called components, from data gathered for a set of items in such a way as to show the data's simplified internal structure and reduce the number of variables while sacrificing the minimum of the original information. The data we gathered were found to cluster into four components explaining 51% of the variance: Simple Technologies, Energy Technologies, System Technologies, and Non-Technologies. Students engaged in EiE were more likely than the control group to choose Simple Technologies and System Technologies as technologies (Jocz & Lachapelle, 2012). Students' responses to individual items are shown in Figure 2.

The most recent version of the "What is Technology?" instrument has been used by groups of 242 students (Lachapelle, Jocz, & Phadnis, 2011), 508 students (Lachapelle, Hertel, Phadnis, & Cunningham, 2013) and 788 students (Lachapelle, Hertel, Shams, et al., 2013), all from Minnesota, before and after engaging in EiE units. For all groups, scores increased significantly from pre- to post-test; when a control group was used, EiE students improved significantly more than control students. These data reinforced the finding that, even before participating in EiE, students can correctly categorize non-technologies and electronic technologies, but have a tendency to incorrectly identify non-electronic technologies. This tendency does not appear as strongly on post-tests, suggesting that students gain a more accurate and nuanced understanding of technology following participation in EiE.

We are currently (2014) analyzing data from another large sample of students who completed the "What is Technology?" instrument by using Structural Equation Modeling. Through this analysis, we hope to gain an even clearer picture of students' conceptions and misconceptions about the nature of technology as well as confirmation of the value of the instrument.

Figure 2: Elementary Students' Conceptions of Technology



Teacher Conceptions: *How do teachers describe technology?*
Teachers who have completed the same assessments as students show a similar pattern of responses, though their conception of technology is much more likely to be congruent with the definition of technology as "any thing or process that humans have created to meet human needs or desires" (C. M. Cunningham & Lachapelle, 2007; Christine M. Cunningham, Lachapelle, & Keenan, 2010).

Measuring the Impact of EiE on Students

Impact of EiE on Student Understanding of Engineering and Science Concepts

During the development, pilot testing, and field testing of each EiE unit, we arranged for students in grades 2-5 who were engaged in that unit to complete a pre- and post-assessment. Questions measured knowledge of (a) general engineering and technology concepts, (b) concepts specific to the engineering field of focus in that unit, (c) engineering and technology concepts that are taught in the unit, and (d) the science concepts relevant to and reinforced by the unit.

The first round of analysis of student results from the pre-and post-assessments of the first six EiE units found that, on more than 75% of questions, EiE students performed significantly better on the post-assessment than on the pre-assessment. In most cases where a control sample was available for comparison, EiE students performed significantly better than the control. This was true for both genders and all racial/ethnic groups (Lachapelle, 2007). An analysis of improvements made by students whose teachers participated in the Pre-College Engineering for Teachers (PCET) professional development project found similar results (Lachapelle, Cunningham, Oware, & Battu, 2008). After completing an EiE unit, students demonstrated the following:

- a better understanding of the specific kind of tasks that engineers working in a specific field (e.g., environmental engineers) might do for their job
- a better understanding that engineering involves design and teamwork
- a better grasp of relevant engineering and technology vocabulary

- a better understanding of the engineering design process
- a better understanding of materials, their properties, and their uses in engineering design scenarios
- an increased likelihood of understanding science content related to the unit
- a better understanding of how to improve technologies
- a better understanding of what a process is and how it is a type of technology
- a better understanding of the criteria for judging the effectiveness of a technology (Lachapelle, 2007; Lachapelle et al., 2008)

A second round of analysis of units 7 through 15 compared EiE student performance against control groups, using HLM methodologies for 7 of the 9 units (the other 2 units had insufficient sample sizes for HLM analysis). HLM is an approach to modeling data that incorporates dependent variables at multiple levels of analysis—in this case, at the individual student level and at the classroom and teacher level—into one model, to better account for variance in the data and more accurately measure the effects of variables. Modeling again found that EiE students

- improved significantly on assessments
- performed significantly better on post-assessments than control group students did when pre-assessment performance was taken into account
- performed significantly better than control group students on science questions, where a subgroup of science questions was available for analysis

Details of findings can be found in Table 1 (Lachapelle, Cunningham, Jocz, Kay, et al., 2011).

Table 1: Effect Sizes for Classroom Participation in EiE Field Test Units 7-15
Note: >.2 indicates a small treatment effect and a measure of >.6 indicates a large effect.

Unit	Outcome	Treatment Effect Size	Pre Class Mean Effect Size	Topics Assessed
7: Designing Alarm Circuits	PostAll	0.372	0.257	interpret schematic diagrams of circuits; identify aspects of electrical engineering; & science topics (below)
	PostScience	0.470	0.273	electrical current; insulators; conductors; forms of energy
9: Seeing Animal Sounds	PostAll	0.420	0.301	how to change sounds; how to represent sounds; how different materials affect sound; aspects of acoustical engineering; & science topics (below)
	PostScience	0.311	*	properties of sound: pitch, volume, duration
10: Evaluating a Landscape	PostAll	1.367	0.272	geotechnical engineering; foundation design; models; erosion
	PostScience	1.070	0.356	erosion
11: Designing Maglev Systems	PostAll	2.339	0.408	aspects of transportation engineering; design of maglev transportation systems; properties of magnets
13: Designing Plant Packages	PostAll	0.324	0.272 By treatment: 0.218	Packages; package engineering; needs of plants; functions of plant structures
14: Designing Solar Ovens	PostAll	0.689	0.570	green engineering; how solar ovens work; heat energy; insulation
15: Designing Parachutes	PostAll	1.292	0.551	design and operation of parachutes; aerospace engineering; & science topics (below)
	PostScience	1.045	0.456	atmospheric properties; the effects of drag on falling objects

*Variable tested but not significant.

A third round of analysis of units 16 through 20 compared EiE student performance on post-assessments against the pre-assessment, using t-tests and confidence intervals—a control group was not available. Dependent-sample t-tests determine whether the post-assessment scores are significantly likely to be greater than pre-assessment scores, with 95% confidence. Analysis found that EiE students participating in all 5 units:

- Improved significantly on engineering questions ($p<0.001$, all scales)
- Improved significantly on science questions ($p<0.001$, all scales)

Table 2 presents detailed findings (Lachapelle, Cunningham, Jocz, Phadnis, et al., 2011).

The measured effect of participation in EiE units 7 – 15 on scores ranged from small to large across units; however, effect sizes are likely to be somewhat inflated for "PostAll" scores, which included engineering questions, since the control group did not receive engineering instruction. Similarly, significance of changes pre- to post- on engineering questions for students participating in EiE units 1 – 6 and 16 – 20 are likely to be inflated. For this reason, and also because the data was collected from convenience samples (not randomized samples) of field test and control classrooms, or not compared to control samples, these findings are promising but not conclusive (Lachapelle, 2007; Lachapelle, Cunningham, Jocz, Kay, et al., 2011).

Table 2: Reference Group Change in Score for EiE Field Test Units 16 – 20
Note: A p-value <0.01 indicates 99% or greater probability that students scores improved.

Unit	Topic Assessed	Change in Score (Reference Gp)	95% CIs	t	df	p-value
16: Cleaning Up an Oil Spill (CO)	Environmental Engineering	1.65	[1.47, 1.82]	18.711	57	<0.001
	Science (Food Webs)	2.00	[1.74, 2.27]	15.052	57	<0.001
	Pollution	1.15	[1.01, 1.30]	16.062	58	<0.001
17: Replicating an Artifact (RA)	Properties of Materials	1.20	[1.01, 1.39]	12.565	60	<0.001
	Rocks	2.84	[2.60, 3.08]	23.598	61	<0.001
18: Designing Submersibles (SB)	Ocean Engineering	1.86	[1.57, 2.15]	12.876	36	<0.001
	Science (Sinking & Floating)	1.27	[1.01, 1.53]	9.880	37	<0.001
19: Designing Knee Braces (KB)	All	3.46	[3.20, 3.72]	26.864	604	<0.001
	Biomedical Engineering	1.50	[1.40, 1.59]	31.862	605	<0.001
	Models	1.09	[0.97, 1.22]	17.797	604	<0.001
	Science (Bones & Muscles)	0.95	[0.81, 1.08]	13.983	604	<0.001
20: Designing Lighting Systems (LS)	Optical Engineering	0.76	[0.56, 0.96]	7.527	55	<0.001
	Engineering Design	0.38	[0.29, 0.47]	8.556	55	<0.001
	Properties of Light	0.59	[0.47, 0.71]	9.540	56	<0.001
	Brightness & Movement of Light	0.91	[0.73, 1.10]	10.060	53	<0.001

Data from a study of the use of EiE in Minneapolis and Hopkins, Minnesota, from 2009 – 2013 provide further evidence for the potential positive effects of the curriculum on student learning in science and engineering (Lachapelle, Jocz, & Phadnis, 2011; Lachapelle, Hertel, Phadnis, et al., 2013; Lachapelle, Hertel, Shams, et al., 2013). Student responses on content-specific instruments before and after participating in an EiE unit (including Designing Maglev Systems, Designing Water Filters, Designing Model Membranes, Seeing Animal Sounds, Cleaning an Oil Spill, and Making Work Easier) in many cases showed significant improvement in science and engineering scores from pre- to post-test. Like the earlier pilot test, this study should be considered promising but not conclusive, as most analyses did not include control data.

Impact of EiE on Students' Interest in and Attitudes towards Science and Engineering Careers: *Are students exposed to EiE more likely to consider careers in science and engineering?*

Students who completed the Engineering is Elementary curriculum were significantly more likely than control students to report interest in being an engineer on the post-survey. They were also significantly more likely than control students to report interest in and comfort with engineering jobs and skills, and to agree that scientists and engineers help to make people's lives better (Christine M. Cunningham & Lachapelle, 2010). This improved interest in engineering has been confirmed by a later study, which also found that student demographics have minimal effect on this interest (Lachapelle, Phadnis, Jocz, & Cunningham, 2012).

The responses of boys and girls changed similarly in direction and size from the pre-survey to the post-survey, but girls' and boys' responses overall were significantly different on all questions regarding engineering jobs. Boys showed more interest than girls in the questions having to do with inventing, figuring things out, cars, and structures; girls showed more interest in the jobs to do with helping society and people. In addition, both boys and girls were significantly more likely to agree that they would enjoy being an engineer after completing an EiE unit, but boys reported more interest than girls on both the pre- and post-survey (Christine M. Cunningham & Lachapelle, 2010). The gender differences between inventing and helping, as well as EiE's effect on interest in engineering careers, have been confirmed by a later study. This same study showed that while the increases in reported enjoyment of being an engineer were significant for both boys and girls, the positive effect of EiE on girls' reported interest was significantly more than for boys (Lachapelle, Phadnis, Jocz, et al., 2012).

These potential effects of EiE on student attitudes about engineering careers are reinforced by data collected in Minnesota during 2009-2010 (Lachapelle, Jocz, et al., 2011). The 2010-2011 school year of data from these same sites also provided evidence for these effects. Changes from pre-EiE to post-EiE surveys showed students responding significantly more positively after EiE to statements about science and engineering, specifically as professions that help people and as enjoyable future careers (Lachapelle, Hertel, Phadnis, et al., 2013).

Impact on Underrepresented/Under-served Students: *Does the curriculum serve all learners?*

Teachers participating in the Pre-College Engineering for Teachers (PCET) professional development project reported that EiE works well with all students, whether low- or high-achieving, including students with cognitive challenges, linguistic challenges, and behavioral challenges; students who are gifted and talented; girls; children of color; and students who are at risk in other ways. When considering all these populations teachers agreed most strongly that the curriculum worked with children of color (Faux, 2008).

A small study of teachers' perceptions of the impact of EiE on students from groups historically underrepresented in STEM fields (females, low-income, historically underrepresented minorities, IEP, English Language Learners) found the majority of the 46 teachers responding indicated student engagement as well as performance in EiE was higher than it was in science. For some but not all groups, most teachers indicated that engagement in EiE was also higher than it was in school in general. Between 30 and 52 percent of teachers (percentages varied depending upon the student sub-group considered) also indicated that performance in EiE was higher than it was in school in general. Most teachers also reported that using EiE had a positive impact on student interest in science, engineering, and mathematics, as well as student engagement and performance in school (Weis & Banilower, 2010). A large-scale study of field test versions of EiE units 7 – 15 provides further evidence that EiE works well for all students. In most cases, demographic variables– including whether a student has limited English proficiency (LEP), receives free or reduced-price lunch (FRL), has an Individualized Education Program (IEP), or is from an underrepresented minority group (Is_Black or Is_Hispanic)– were associated with poorer performance on both pre- and post-assessments, but this relationship was not moderated by treatment: the difference was the same for both the control and test groups (Lachapelle, Cunningham, Jocz, Kay, et al., 2011). A later study (Lachapelle, Phadnis, Jocz, et al., 2012), has returned similar results: student demographics rarely affect interest in and attitudes about engineering and related fields. Regardless of demographics, students who engaged with EiE were more likely to report that they "know what engineers do for their jobs" following participation (Lachapelle, Phadnis, Jocz, et al., 2012). While girls and boys, showed interest in different types of engineering activities regardless of their participation in EiE, (girls preferring helping people and the environment, and boys preferring inventing and figuring things out), both girls and boys were more likely to report that they "would enjoy being and engineer when [they] grow up"; the effect that EiE had on girls for this attitude towards engineering careers was even more pronounced than for boys (Lachapelle, Phadnis, Jocz, et al., 2012).

Teachers' Perception of the EiE Curriculum

Teachers who use EiE in their classrooms rate the EiE curricular materials highly (Carson & Campbell, 2007a, 2007b; Faux, 2007; Lachapelle, Cunningham, Jocz, Kay, et al., 2011). Teachers participating in the Pre-College Engineering for Teachers (PCET) professional development project strongly and significantly agreed that EiE units are well designed, that the EiE units they used fit into the required curriculum, rather than being "one more thing' to teach, and that EiE units are well matched to the level of students (Faux, 2007). Teachers participating in field testing of EiE units 7 through 20 similarly agreed that EiE units furthered their objectives for science and engineering, positively affected their students' motivation, and are age-appropriate (Lachapelle, Cunningham, Jocz, Kay, et al., 2011; Lachapelle, Cunningham, Jocz, Phadnis, et al., 2011). The same reports found that teachers consistently gave high ratings to EiE for reinforcement of science learning objectives, and also cited other connections to literacy, math, and social studies as valuable in free response.

After using the EiE materials with their students, PCET teachers and field test teachers highly rated other aspects of EiE, indicating that they would do the unit again with their class, that they found the directions clear, and that they felt comfortable leading the lessons (Carson & Campbell, 2007a; Lachapelle, Cunningham, Jocz, Kay, et al., 2011). PCET teachers additionally agreed that the science and literacy connections were useful, that overall they found the materials for the activities were easy to get, and that students were able to successfully complete the design challenge (Carson & Campbell, 2007a).

Teachers see the EiE materials as an excellent fit for elementary school students and teachers, most often citing as strengths the hands-on approach, the sound pedagogical design of the units, the ease with which they can be adapted to fit local circumstances, the collaborative nature of the activities, and the many ways in which using the EiE units promotes a greater awareness of the ubiquity of engineering in the lives of the students. Concerns about the units, when voiced, focused on the length of time required to do the lessons, the acquisition and management of material resources to support the lessons, and the reading level of the EiE stories (Faux, 2006; Lachapelle, Cunningham, Jocz, Kay, et al., 2011; Lachapelle, Cunningham, Jocz, Phadnis, et al., 2011).

When asked to compare their experiences teaching EiE and traditional elementary science curricula, PCET teachers strongly agreed that with EiE, students learn science concepts better, are more engaged, are more collaborative, are more creative, and make real world science/engineering connections (Faux, 2008). When asked "How did your students benefit, academically or otherwise, from taking part in this unit?" many EiE field test teachers indicated that EiE units provide opportunities for students to learn more about science and engineering, and that their students did learn unit-specific science and engineering content (Lachapelle, Cunningham, Jocz, Kay, et al., 2011; Lachapelle, Cunningham, Jocz, Phadnis, et al., 2011). In the same reports, many teachers also mentioned that their students gained a deeper understanding of the work of an engineer and were better able to recognize engineering in everyday life. A number of field test teachers also described how their students' problem solving, critical thinking, teamwork, and communication skills were improved. Another common response was that students enjoyed the unit and were engaged, especially with hands-on activities.

Impacts of EiE Professional Development and EiE Implementation on Teachers

EiE is very interested in the effect of professional development and implementation of an EiE unit on teachers and their pedagogies. In general, EiE staff conduct a workshop evaluation at each program we offer—most of our data to date came from teachers who have both attended professional development and implemented a unit in the classroom. We have not yet teased apart the relative influence of these two experiences on teachers' responses.

Because EiE was initially funded as a curriculum development program that would not require professional development for implementation, one evaluation study did examine whether both trained and untrained teachers could use the materials effectively. This study revealed that teachers found it easy to implement the EiE curricular materials, even without training. Both types of teachers indicated that they were comfortable doing the units, felt their knowledge after reading the unit guide was adequate to do the units, and believed that their students were successful in completing the design challenges (Carson & Campbell, 2007b).

Teachers are Satisfied with Professional Development Programs

EiE staff have offered hundreds of professional development programs to thousands of teachers and have also trained hundreds of teacher educators who do EiE professional development in diverse localities across the country. Professional development programs may range from two hours to more than two weeks long.

Teachers consistently express a high degree of satisfaction with EiE professional development services. They strongly agree that workshops are well planned and structured, that they are learning by doing, and that the EiE units and materials are presented in a manner that helps them feel comfortable using them in their classroom. Teachers say they feel the workshops, prepare them to do an engineering project in their classroom (Faux, 2007).

Teacher Gains in Knowledge of Engineering and Technology

Teachers also report large gains in their engineering knowledge and understanding as a result of participating in professional development programs and using EiE. They indicate significant increases in their knowledge and understanding of the range of engineering disciplines, of what engineers do, and of the pervasiveness of engineering in our society. Teachers also report that they become knowledgeable about how engineering is practiced, understand there is not necessarily one "right" answer for engineering problems, know about the engineering design process, know more about the types of constraints that influence the design and selection of engineering criteria, and are more confident in their ability to analyze the engineering solutions that their students might generate (Faux, 2007). Their understanding of engineering changes as well; after participating in EiE, the number of teachers including design, problem solving, and process/design process as part of their definitions of engineering increased dramatically (Carson & Campbell, 2007a).

Teachers' open-ended responses about engineering and technology were closer to standards-based definitions in a post-survey (completed after participating in an EiE professional development workshop and teaching at least one EiE unit) than in a pre-survey. Before participating in EiE, teachers were more likely to define technology in terms of examples, particularly tools, machines, computers and electronics, and less likely to define technology as a solution to a problem or as something designed or invented. Before participating in EiE, teachers were slightly more likely to identify engineering as building or constructing and less likely to define it as problem solving, as a process in itself, as having to do with improving things and processes, or as having to do with math and/or science. Teachers also reported making greater use of engineering concepts and examples, including the engineering design process, across STEM subjects after participating in EiE (Christine M. Cunningham et al., 2010).

Teachers Report Changes in Their Pedagogy as a Result of EiE

Teachers report changes in their pedagogies after learning about EiE and teaching it in their classrooms. Interestingly, teachers report changes in their engineering teaching, their science and math teaching, and their pedagogical strategies more generally. Such changes, particularly across such a wide range of fields, are rare in education and professional development.

After participating in EiE, teachers significantly increase their use of engineering in their teaching in both science and other content areas. Particularly large increases were found in the frequency with which teachers describe engineering careers to their students, use engineering examples in science lessons, and, most impressively, use an engineering design process in their science classes. They also discuss the courses and skills needed to enter engineering. Teachers are also significantly more apt to use an engineering design process in other areas—in math lessons and science lesson as well as content areas outside of math and science (Faux, 2008).

For years, educators have been trying to help teachers develop children's problem-solving capacity. EiE seems to offer one successful possibility. External evaluations (Carson & Campbell, 2007a; Faux, 2007) have also found that teachers report changes in their pedagogical strategies. After participating in EiE, teachers significantly increase their use of problem-solving strategies not explicitly related to engineering in their teaching. After using EiE, teachers show improved attitudes toward problem-solving strategies and use more inductive methods (Faux, 2006, 2008). They also significantly increase their use of four other problem-solving strategies. They are more likely to have their students ask what they know related to the topic being studied, use things from every-day life in solving problems, work on problems for which there is no immediately obvious method of solution, and explain how they solve complex problems (Faux, 2008).

Teachers report significant changes in their use of engineering examples and the engineering design process in science, math, and other content areas. They increase the time they spend on complex and open-ended problems with their students and increase the amount of explanation of solutions they require of their students. Over the course of implementation, the reasons teachers offer for wanting to do more engineering in the classes expands from simply introducing their students to engineering to include more of a focus on problem-solving and on incorporating more real-life topics.

One of the external evaluators ended his report this way: "It is rather rare in education program evaluation to view such a large and far-flung undertaking be so consistently and strikingly successful as [the EiE summer workshops]. The data are clear in underscoring the truly stunning degree to which the workshop program met its core objectives. Participants spoke effusively and often of the tremendous gains they had made, the revelatory quality of their newfound appreciation for engineering, and the clarity of their understanding on how to introduce EiE materials in their classrooms" (Faux, 2007).

Out of School Time Curricula

We use data collected from EiE's out-of-school-time (OST) curricula primarily for formative evaluation. During pilot testing of the Engineering Adventures (EA) units (designed for 3rd – 5th graders) and the Engineering Everywhere (EE) units (designed for 6th – 8th graders), educators complete extensive feedback forms and administer a modified version of the Engineering Attitudes instrument to children participating in their afterschool or camp program. We also collect and review the engineering journals that children are provided during the experience. The feedback from educators and site observations directly informs revisions of the curricula prior to public release.

Educators rate the EiE OST units very highly. A survey of 118 people who downloaded the EA "Bubble Bonanza" unit showed 95% of respondents rated the unit's ease of use as a 5, 6, or 7 on a 7-point scale (1 = "not at all easy," 7 ="very easy"). Those surveyed also rated the overall quality of the unit as high, with 100% of survey respondents rating the unit a 5, 6, or 7 (1 = "very low quality," 7 = "very high quality"). All respondents indicated that they would also like to implement other EA units (Higgins, Hertel, Lachapelle, & Cunningham, 2013). Similar surveys are being conducted for other EA units and are planned for EE units.

The data collected from the EA instrument suggests that children participating in EA units may experience changes similar to the ones children using EiE experience. Children participating in EA pilot testing in camps during the summer of 2012 showed a significant increase from pre- to post-test in agreement with the statements "I would enjoy being a scientist when I grow up," "I would enjoy being an engineer when I grow up," and "Engineers help make people's lives better as part of their jobs" (n=476) (Higgins et al., 2013). Further analysis is currently underway on the attitudes data from EA and EE.

Qualitative analysis of student journals also suggests that participating in EA's design challenges supports children's use of developmentally appropriate engineering practices. Most children participating in the Bubble Bonanza unit were able to make designs that met their stated goals, and nearly all of them seemed to incorporate what they learned while exploring the properties of the materials (Higgins et al., 2013). Anecdotal evidence gathered while observing the culminating showcase of the design challenges reinforces that children are authentically engaging in engineering practices and reflecting on the engineering design process while participating in EA.

Other Research: Independent & External Research Contributions

"The Smart Study": University of North Carolina-Greensboro School of Education
A small, qualitative study conducted in low-income, high-minority urban settings in North Carolina is exploring how student and teacher ideas of "smartness" in the classroom may change as students and teachers begin to engage with EiE (Hegedus, Carlone, & Carter, 2014). Students considered "smart" in engineering exhibited different qualities (e.g. persistence, creativity) than those considered "smart" by traditional measures (for example, high achievers). Some students who were generally considered low or moderate achievers came to be considered "smart engineers," a result that surprised their teachers

and other students.

"Perspectives on Failure" Named "Best Paper" by ASEE in 2014
A mixed-methods study focused on teachers' and students' views of failure in the context of the classroom and new implementation of engineering (Lottero-Perdue & Parry, 2014) was recognized as "Best Paper" at the 2014 annual conference of the American Society for Engineering Education (ASEE). Researchers interviewed 38 teachers had been randomly assigned to implement either EiE or a comparison engineering curriculum about their perspectives on failure. They found that while failure is something teachers generally want to avoid in education, as it is generally associated with assessment and accountability, the experience of implementing engineering in the classroom may lead teachers to reconsider how they think about the concept of failure, especially as it may lead to growth and valuable learning experiences. "Failure" as a term has different meanings and connotations in the contexts of education and engineering, and teachers struggled with this cultural shift.

Current and Ongoing Research Efforts: NFS-sponsored Efficacy Study

EiE staff and external evaluators continue to evaluate and research the Engineering is Elementary project. Student assessment continues as part of the development process to ensure that each unit, as designed and implemented can, in fact, meet its stated learning objectives. EiE's evaluation process continues to evolve (Lachapelle & Cunningham, 2010). A number of the pilot studies reviewed here have revealed very interesting, sometimes unanticipated effects of the EiE materials and professional development and merit detailed, larger-scale studies that we hope to conduct. The EiE project is currently undertaking a rigorous efficacy study supported by the National Science Foundation, further examining EiE impacts on students and teachers by making direct comparisons with other curricula. The scope of this effort spans three geographic regions and involves over 300 teachers and 700 classrooms. High-needs schools make up a large proportion of the sample. Results of this study will be available by 2017.

References

Carson, R., & Campbell, P. B. (2007a). Museum of Science: Engineering is Elementary; Exploring the impact of EiE on participating teachers. Groton, MA: Campbell-Kibler Associates, Inc.

Carson, R., & Campbell, P. B. (2007b). Museum of Science: Engineering is Elementary; Impact on teachers with and without training. Groton, MA: Campbell-Kibler Associates, Inc.

Cunningham, C. M., & Lachapelle, C. P. (2007). Engineering is Elementary: A global perspective on engineering for children. In ASEE Global Colloquium. Rio de Janeiro, Brazil.

Cunningham, C. M., & Lachapelle, C. P. (2010). The impact of Engineering is Elementary (EiE) on students' attitudes toward engineering and science. In ASEE Annual Conference and Exposition. Louisville, KY.

Cunningham, C. M., Lachapelle, C. P., & Keenan, K. (2010). Elementary teachers' changing ideas about STEM and STEM pedagogy through interaction with a pedagogically-supportive STEM curriculum. In P-12 Engineering and Design Education Research Summit. Seaside, OR. Retrieved from http://www.mos.org/eie/pdf/research/Cunningham_R1362.pdf

Cunningham, C. M., Lachapelle, C. P., & Lindgren-Streicher, A. (2005). Assessing elementary school students' conceptions of engineering and technology. In ASEE Annual Conference and Exposition. Portland, OR.

Faux, R. (2006). Evaluation of the Museum of Science PCET Program: Interim report. Somerville, MA: Davis Square Research Associates.

Faux, R. (2007). Evaluation of the Museum of Science PCET Program Interim report. Somerville, MA: Davis Square Research Associates.

Faux, R. (2008). Evaluation of the Museum of Science PCET Project: Evaluation Report. Somerville, MA: Davis Square Research Associates.

Hegedus, T., Carlone, H. B., & Carter, A. (2014). Shifts in the cultural production of "smartness" through engineering in elementary classrooms (works in progress). In Proceedings of the American Society of Engineering Education. Indianapolis, IN.

Higgins, M., Hertel, J., Lachapelle, C. P., & Cunningham, C. M. (2013). Engineering Adventures Curriculum Development Grant. Boston, MA: Museum of Science. Retrieved from http://eie.org/sites/default/files/research_article/research_file/bechtelreportforweb.pdf

Jocz, J., & Lachapelle, C. (2012). The Impact of Engineering is Elementary (EiE) on Students' Conceptions of Technology. Boston, MA: Museum of Science.

Knight, M., & Cunningham, C. M. (2004). Draw an Engineer Test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. In ASEE Annual Conference and Exposition. Salt Lake City, UT: American Society for Engineering Education.

Lachapelle, C. P. (2007). Engineering is Elementary: A national evaluation of years 2-3. Boston, MA: Museum of Science.

Lachapelle, C. P., & Cunningham, C. M. (2007). Engineering is Elementary: Children's changing understandings of science and engineering. In ASEE Annual Conference & Exposition (p. 33). Honolulu, HI: American Society for Engineering Education.

Lachapelle, C. P., & Cunningham, C. M. (2010). Assessing elementary students' understanding of engineering and technology concepts. In ASEE Annual Conference and Exposition. Louisville, KY.

Lachapelle, C. P., Cunningham, C. M., Jocz, J., Kay, A. E., Phadnis, P., Wertheimer, J., & Arteaga, R. (2011). Engineering is Elementary: An evaluation of years 4 through 6 field testing. Boston, MA: Museum of Science.

Lachapelle, C. P., Cunningham, C. M., Jocz, J., Phadnis, P., Wertheimer, J., & Arteaga, R. (2011). Engineering is Elementary: An evaluation of years 7 and 8 field testing. Boston, MA: Museum of Science.

Lachapelle, C. P., Cunningham, C. M., Oware, E. A., & Battu, B. (2008). Engineering is Elementary: An evaluation of student outcomes from the PCET program. Boston, MA: Museum of Science.

Lachapelle, C. P., Hertel, J. D., Phadnis, P., & Cunningham, C. M. (2013). Evaluating the Impact of Engineering is Elementary: Year 2 of Implementation in Minneapolis and Hopkins Public Schools (p. 53). Boston, MA: Museum of Science. Retrieved from http://www.mos.org/eie/pdf/research/Cargill_Year1_Report.pdf

Lachapelle, C. P., Hertel, J. D., Shams, M. F., & Cunningham, C. M. (2013). Evaluating the Impact of Engineering is Elementary: Years 3 and 4 of Implementation in Minneapolis and Hopkins Public Schools. Boston,: Museum.

Lachapelle, C. P., Jocz, J., & Phadnis, P. (2011). An evaluation of the implementation of Engineering is Elementary in fourteen Minneapolis Public Schools (p. 53). Boston, MA: Museum of Science. Retrieved from http://www.mos.org/eie/pdf/research/Cargill_Year1_Report.pdf

Lachapelle, C. P., Phadnis, P., Hertel, J., & Cunningham, C. M. (2012). What is engineering? A survey of elementary students. Presented at the 2nd P-12 Engineering and Design Education Research Summit, Washington, D.C.

Lachapelle, C. P., Phadnis, P., Jocz, J., & Cunningham, C. M. (2012). The impact of engineering curriculum units on students' interest in engineering and science. Presented at the NARST Annual International Conference, Indianapolis, IN.

Lottero-Perdue, P. S., & Parry, E. A. (2014). Perspectives on Failure in the Classroom by Elementary Teachers New to Teaching Engineering. Presented at the 121st ASEE Annual Conference & Exposition, Indianapolis, IN.

Weis, A. M., & Banilower, E. R. (2010). Engineering is Elementary: Impact on historically-underrepresented students survey results. Chapel Hill, NC: Horizon Research, Inc.