Engineering is Elementary:
An Evaluation of Student Outcomes from the PCET Program

Dr. Cathy P. Lachapelle
Dr. Christine M. Cunningham
Dr. Euridice A. Oware
Bharat Battu

Engineering is Elementary
Museum of Science, Boston

December, 2008

Engineering is Elementary
Museum of Science, 1 Science Park
Boston, MA 02114

Museum of Science

This material is based upon work supported by the National Science Foundation under Grant No. 0454526. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Abstract

Teachers attending the Pre-College Engineering for Teachers (PCET) program in the summer of 2007 learned more about engineering and how to instruct their students in elementary-level engineering using the *Engineering is Elementary* (EiE) curriculum. The participating teachers collected control data from their students before attending the one-week PCET summer institute—they conducted the pre-assessment, taught a science topic (but not the related engineering unit), and then conducted a post-assessment. The academic year after they attended the PCET professional development program they collected test data from their students. In this case they conducted a pre-assessment, taught the science and the relevant EiE engineering unit, and then conducted the post-assessment. Analysis of these data show that students in the field test year who received both science and EiE instruction developed a better understanding of science, engineering, and technology concepts and showed more interest in science and engineering as careers than students in the control year who received only science instruction.

Engineering is Elementary and the PCET Program

Engineering is Elementary (EiE) is a research-based curriculum and professional development project focused on creating curriculum units covering topics in engineering and technology as a supplement to core science instruction. Each EiE curriculum unit is designed to build on and reinforce one science topic through the exploration and development of a related technology. For example, in the Designing Bridges unit, students design bridges, drawing on what they are learning about forces acting on physical structures. Each EiE unit has common elements, including a four-lesson structure. The first lesson introduces a field of engineering and a design challenge through a fictional story. The second lesson explores the field of engineering more broadly through hands-on activities. The third lesson includes a controlled experiment for more in-depth exploration of different materials, processes, or design elements that will inform the final design. For the fourth lesson, students plan, create, test, evaluate and improve their designs [1].

The goal of the *Pre-College Engineering for Teachers* (PCET) project was to introduce teachers to engineering concepts and pedagogy through summer professional development workshops. In the first years of the project, high school teachers attended the PCET summer institutes. Middle school teachers attended in later years, and in the final three years of the project, elementary school teachers attended. The PCET summer institutes for elementary school teachers introduced teachers to engineering using the *Engineering is Elementary* (EiE) curriculum. During each summer institute, teachers went on field trips and listened to lectures by practicing engineers. They also engaged with a number of the EiE curriculum units, trying the hands-on activities and design challenges themselves, and discussing how they would implement the units in their classrooms. During the school year after the summer institutes, teachers were given EiE curriculum materials and encouraged to try the units in their classrooms. They were invited to a final meeting day in the spring to discuss their engineering teaching experiences.

The Research Program

The 2007 PCET summer institutes were the final workshops of the program. Teachers were recruited for the 2007 PCET summer institutes in January 2007. All applicants teaching grades 2-5 were required to administer EiE pre- and post-assessments during the spring for any science units they were teaching. (Previous experience has demonstrated that written data from Grade 1 students are not reliable and therefore we do not collect surveys from them.) After attending the summer institutes, teachers received EiE curriculum materials for classroom implementation during the 2007-2008 school year. They were also required to collect pre- and post-assessments for the EiE units they taught. The purpose of this data collection was to have a pool of data from the same teachers, before and after they taught EiE in conjunction with their science units, so the effect of EiE instruction by PCET-trained teachers could be measured.

Pre-assessments were collected in the winter of 2007 (January through March). Post-assessments were collected from the same students in May and June of 2007, after science instruction was completed. Each teacher received assessments for their students which matched the science topics they were covering during the spring. This sample comprises the control sample described in the sections to follow. Pre-assessments for the field test sample (students receiving EiE instruction) were administered during the fall of 2007, before EiE and related science instruction began. Post-assessments were administered to these students approximately zero to four weeks after EiE instruction was completed—sometime between December and June of the 2007-2008 school year.

Each participating EiE test student and control student received one assessment that focused on general engineering and/or an "engineering attitudes" survey, as well as a unit assessment specific to the science/engineering they studied. Every student in a classroom received the same assessments. Unit-specific pre- and post-assessments consist of eight to twelve multiple-choice questions, including both science and engineering questions that are relevant to the unit. The engineering attitudes survey consists of twenty statements, where students are asked to indicate their agreement/disagreement on a five-point Likert scale. The general engineering survey consists of four multiple-choice vocabulary questions, as well as five engineering design scenarios, where students are asked to indicate the step of the engineering design process taking place from a multiple-choice list. The general engineering survey results are not reported here.

The data reported here focus on five EiE units that were used during the 2007-8 school year:

- Designing Bridges
- Designing Walls
- Designing Windmills
- Making Work Easier
- Hand Pollinators

The results demonstrate that for each of these units, EiE students learned the science and engineering concepts. We also present results from the Engineering Attitudes assessment. The instruments can be found in the Appendices.

The Student Samples

Responses from students of PCET teachers who were engaged with the EiE units (called EiE or test below) were compared to responses from the control sample. Both the test sample and the control sample received science instruction after completing the pre-assessments and before completing post-assessments. The test sample completed the EiE engineering curriculum in addition to their regular science curriculum.

Because EiE was implemented in regular elementary school generalist classrooms and science specialist classrooms, boys and girls participated in roughly equal numbers on each of the assessments. Only grades 2 through 5 (see Table 1) were represented in the sample for each assessment. Very few grade 6 students participated—all of them in the control samples. Grade 2 students participated in the unit-specific assessments; they received a smaller number of questions than older students, and some of their questions were different from what grade 3-5 students received. The specific differences for each unit assessment are described in each unit section to follow.

Table 1. Sample Size by Assessment, by Grade

	Engineer-ing Attitudes	Designing Bridges	Designing Walls	Designing Windmills	Making Work Easier	Hand Pollinators	TOTAL
Gr. 2 – Control	-	90	41	19	145	73	368
Gr. 2 – Test	-	46	106	51	35	134	372
Gr. 3 – Control	-	97	38	29	-	109	273
Gr. 3 – Test	-	36	60	35	100	61	292
Gr. 4 – Control	11	58	90	93	121	98	471
Gr. 4 – Test	155	20	21	78	177	145	596
Gr. 5 – Control	95	92	62	159	116	217	741
Gr. 5 – Test	44	151	90	259	605	-	1149
Gr. 6 – Control	44	-	-	-	-	-	44
Gr. 6 – Test	21	-	-	-	-	-	21
TOTAL – Cntrl	150	337	231	300	382	497	1897
TOTAL – Test	220	253	277	423	917	340	2430

Both control and test samples included primarily non-minority students (see Table 2). Non-minority students comprised more than 80% of the sample for each unit. Unfortunately the small sample sizes of racial/ethnic minorities overall precluded the analysis of the data by racial/ethnic group.

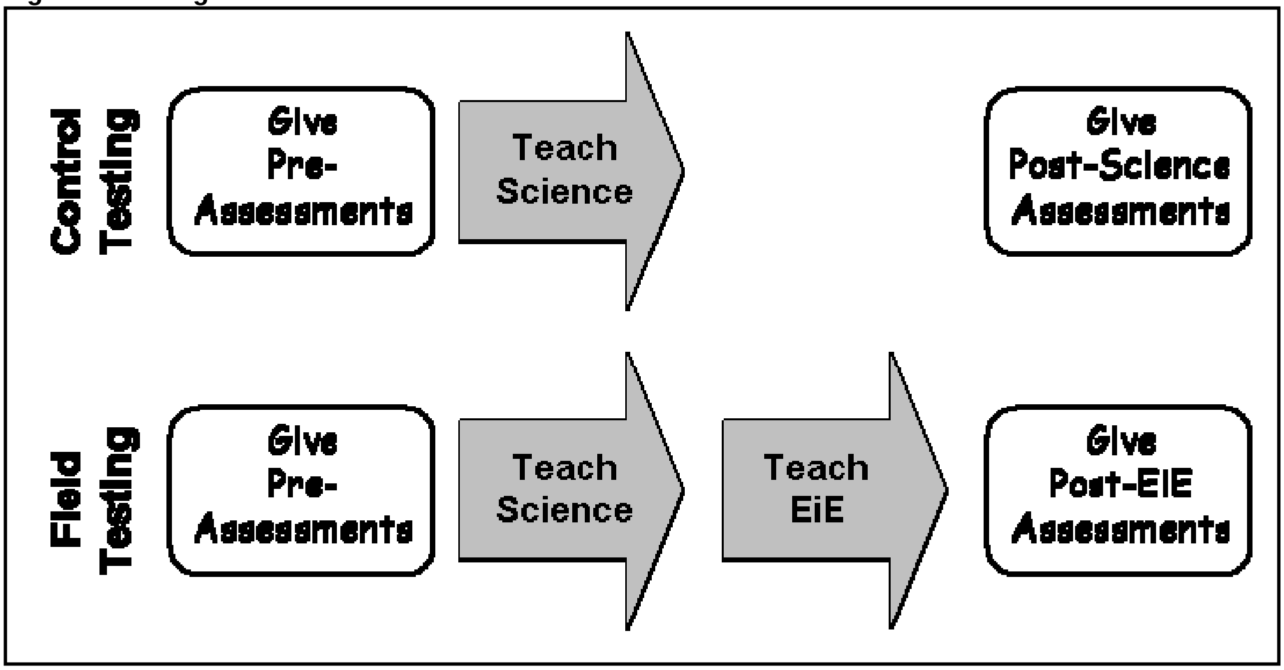
Table 2. Sample Size by Assessment, by Race/Ethnicity

	Engineer-ing Attitudes	Designing Bridges	Designing Walls	Designing Windmills	Making Work Easier	Hand Pollinators	TOTAL
Black – Control	9	8	9	8	6	24	64
Black – Test	7	7	17	12	35	19	97
Asian – Control	2	18	8	35	28	35	126
Asian – Test	15	15	24	43	25	22	144
Hispanic – Control	5	5	5	8	7	10	40
Hispanic – Test	17	6	19	8	15	10	75
White – Control	120	270	193	217	331	420	1551
White – Test	178	188	245	334	802	268	2015
Other – Control	-	10	6	3	4	3	26
Other – Test	1	1	-	6	13	5	26
TOTAL – Control	136	311	221	271	376	492	1807
TOTAL – Test	218	217	305	403	890	324	2357

Pre-Post Differences on Questions

EiE students were tested twice—once before beginning the science curriculum and/or related Engineering is Elementary unit, and once after instruction was completed—allowing for a test-retest analysis (see Figure 1). On the unit-specific assessments, student responses were scored as "correct" or "incorrect" before beginning analysis.

Figure 1. Timing of Assessments in Control and Field Classrooms



Assessment items were combined into scales to test for reliability; principal components factor analysis was run to search for item groupings. Reliability was high for the Engineering Attitudes assessment as a whole, as well as for the *Designing Windmills* assessment. Scales were constructed from composite scores for these assessments. In addition, subscales of composite scores were created for subsets of items that showed high reliability on all but two of the assessments: the Engineering Attitudes assessment, and the unit assessments for *Designing Bridges*, *Designing Windmills*, and *Making Work Easier*. No reliable scales could be found for either the *Designing Walls* assessment, or the *Designing Hand Pollinators* assessment.

Where no scale could be devised, items were analyzed individually for within-group (pre vs. post) differences using McNemar's Test of Symmetry, a crosstabulation analysis designed for binomial nominal data. Differences between the test and control groups were analyzed using the phi coefficient. This χ-square variant is designed for analyzing dichotomous data; its value approaches that of Pearson's χ-square for high values of N, an expectation which was confirmed in this analysis.

For the scales on the Engineering Attitudes and unit assessments, items making up the scales were summed for each student, producing composite scores. These composite scores were tested for normality using the Kolmogorov-Smirnov test and the Sharpiro-Wilk test in SPSS. Since none of the scales showed a normal distribution, they were analyzed using nonparametric statistics. The Wilcoxon Signed Ranks test was used to test for within-group (pre vs. post) differences; the Wilcoxon Mann-Whitney Test was used to test for between-group (control vs. test) differences.

Results for the Engineering Attitudes Questions

Students in grades 3-5 who participated in either EiE or control tests completed the Engineering Attitudes Survey in addition to the unit-specific assessment they were given. The Engineering Attitudes

Survey was originally developed as an assessment of middle school students' knowledge of engineering and their attitudes toward it [2]. The survey was adapted for EiE use; some items were revised to describe work that would more clearly benefit people and society, and the response options were changed from "yes/no/I don't know" to a 5-point Likert scale where: 0=Strongly Disagree; 1=Disagree Somewhat; 2=Not Sure; 3=Agree Somewhat; 4=Strongly Agree.

Engineering Attitudes Survey: Sample Size and Demographic Distribution

Surveys were collected from Massachusetts students in Grades 4-6 (see Table 3). A total of 370 student surveys were analyzed; 220 were completed by EiE (test) students, and 150 by control.

Table 3. Engineering Attitudes Survey: Sample Size by Grade

		Grade			Total
		4	5	6	
Control	Count	11	95	44	150
	% of Sample	7.3%	63.3%	29.3%	100.0%
Test	Count	155	44	21	220
	% of Sample	70.5%	20.0%	9.5%	100.0%
Total	Count	166	139	65	370
	% of Sample	44.9%	37.6%	17.6%	100.0%

Girls comprised 50.0% of the control sample, and 56.4% of the test sample. This difference was not significant (Pearson χ^2 p=.228).

White students made up the bulk of both the control sample (88.2%) and the test sample (81.7%)—see Table 4. Racial/ethnic minorities were slightly better represented in the EiE (test) sample than in the control sample (Pearson χ^2 p=.031). The numbers of racial/ethnic minorities in the sample were insufficient for separate analysis.

Table 4. Engineering Attitudes Survey: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	9	2	5	120	-	136
	% of sample	6.6%	1.5%	3.7%	88.2%	0.0%	100.0%
Test	Count	7	15	17	178	1	218
	% of sample	3.2%	6.9%	7.8%	81.7%	0.5%	100.0%
Total	Count	16	17	22	298	1	354
	% of sample	4.5%	4.8%	6.2%	84.2%	0.3%	100.0%

Engineering Attitudes Survey: Questions and Analysis

Reliability analysis shows this is a highly reliable instrument. Sixteen of twenty items were chosen as the core JOBS scale. These items all asked students about their knowledge of and attitudes towards the work of scientists and engineers, as well as their attitudes towards a variety of jobs and skills associated with engineering. Reliability Analysis of the JOBS scale in SPSS gives this scale a Cronbach's $\alpha = .833$. Additionally, we conducted a principal components factor analysis on the sixteen items of the JOBS scale with Varimax rotation. Factor analysis revealed a consistent pattern of five rotated components in the JOBS scale, each corresponding to between two and five of the twenty survey items: INVENT, HELP SOCIETY, FIGURE THINGS OUT, MAKE LIVES BETTER, and KNOW ABOUT JOBS.

These five components account for 60.4% of the variance in the scale. Student responses to the items contributing to each factor were summed to create composite scores for each of the five factors, which were then used in the analysis.

The remaining four items of the original twenty were combined to form two additional scales, REAL LIFE and CAUSE PROBLEMS. Each was created from highly correlated pairs of items. The REAL LIFE scale has a Cronbach's $\alpha = .729$, and the CAUSE PROBLEMS scale has a Cronbach's $\alpha = .715$.

Two of the twenty questions were reported separately (in addition to being part of the JOBS scale) because of their relevance to the project: "I would enjoy being a scientist when I grow up", and "I would enjoy being an engineer when I grow up". These items are reported as SCIENTIST and ENGINEER.

The text of the questions on the Engineering Attitudes Survey is shown in Table 5. A variety of questions measure students' attitudes toward science and engineering careers and skills, as well as some of their attitudes towards science, math, scientists, and engineers. Items were combined into the item scales designated in the first column.

Table 5. Engineering Attitudes Survey: Survey Questions (Text)

Item Scale	Range of Scale	Text of component questions
REAL LIFE	0-8	Science has nothing to do with real life. Math has nothing to do with real life.
CAUSE PROBLEMS	0-8	Scientists cause problems in the world. Engineers cause problems in the world.
JOBS	0-64	*Consists of the sum of all of the remaining questions*
INVENT	0-12	I would like a job where I could invent things. I would like to help plan bridges, skyscrapers, and tunnels. I would like a job that lets me design cars.
HELP SOCIETY	0-12	I would like to build and test machines that could help people walk. I would enjoy a job helping to make new medicines. I would enjoy a job helping to protect the environment.
FIGURE THINGS OUT	0-16	I would like a job that lets me figure out how things work. I like thinking of new and better ways of doing things. I like knowing how things work. I am good at putting things together.
MAKE LIVES BETTER	0-8	Scientists help make people's lives better. Engineers help make people's lives better.
KNOW ABOUT JOBS	0-8	I think I know what scientists do for their jobs. I think I know what engineers do for their jobs.
SCIENTIST	0-4	I would enjoy being a scientist when I grow up.
ENGINEER	0-4	I would enjoy being an engineer when I grow up.

Student responses are summarized in Table 6. For each scale or item listed in the left-most column, total means and grade-level means are given for both the EiE (test) sample and the control sample. Within-group significance was tested using the Wilcoxon Signed Ranks Test instead of parametric methods because the distribution of all items was found to be non-normal. Exact significance is reported under "p=". P-values significant at $p<.05$ or below are highlighted in bold. Between-group significance for control versus test on the pre-survey and on the post-survey is given in the final two columns; this was tested using the Wilcoxon Mann-Whitney Test.

Table 6. Engineering Attitudes Survey: Results

		Within-Group Differences (Pre vs. Post)								Test / Control Differences	
		EiE Test				Control				PRE	POST
Question	**Group**	**N**	**Pre**	**Post**	**p=**	**N**	**Pre**	**Post**	**p=**	**p=**	**p=**
Science/Math have nothing to do with REAL LIFE[2]	Total	220	1.41	0.91	**.002**	150	0.75	0.75	.897	**.001**	.309
	Gr. 4	155	1.57	0.95	**.002**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	0.47	0.67	.131		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Scientists / Engineers CAUSE PROBLEMS[2]	Total	220	2.34	2.25	.493	150	2.01	2.19	.204	.140	.939
	Gr. 4	155	2.35	2.25	.545	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	1.99	2.20	.175		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Science/Eng JOBS—My preferences & understndng[5]	Total	219	35.21	37.29	**.018**	150	34.65	35.69	.155	.636	.164
	Gr. 4	154	34.39	38.35	**.000**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	35.55	36.22	.420		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Jobs Factor 1: I like to INVENT[3]	Total	220	5.18	5.67	**.035**	150	5.04	5.70	**.010**	.563	.880
	Gr. 4	155	5.04	5.92	**.001**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	4.98	5.94	**.008**		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Jobs Factor 2: I like to HELP SOCIETY[3]	Total	220	6.33	6.29	.935	150	5.79	5.78	.830	.095	.178
	Gr. 4	155	6.24	6.79	**.038**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	5.65	5.60	.905		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Jobs Factor 3: I like to FIGURE THINGS OUT[4]	Total	220	9.72	10.15	.178	150	10.21	10.17	.998	.179	.848
	Gr. 4	155	9.46	10.49	**.003**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	10.44	10.16	.595		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Jobs Factor 4: Scientists/Eng MAKE LIVES BETTER[2]	Total	220	5.74	6.18	**.002**	150	5.69	5.78	.733	.935	**.023**
	Gr. 4	155	5.59	6.01	**.018**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	6.14	6.04	.631		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
Jobs Factor 5: I KNOW ABOUT scientists/ eng'rs JOBS[2]	Total	219	5.14	5.52	**.011**	150	5.14	5.34	.104	.801	.681
	Gr. 4	154	5.21	5.45	.118	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	5.43	5.45	.503		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
I would enjoy being a SCIENTIST[1]	Total	220	1.70	1.67	.841	150	1.38	1.37	.870	**.011**	**.027**
	Gr. 4	155	1.61	1.83	**.042**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	1.42	1.36	.618		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				
I would enjoy being an ENGINEER[1]	Total	220	1.45	1.80	**.000**	150	1.40	1.59	**.039**	.605	.122
	Gr. 4	155	1.31	1.86	**.000**	11	**N too small to report**				
	Gr. 5	44	**N too small to report**			95	1.48	1.67	.079		
	Gr. 6	21	**N too small to report**			44	**N too small to report**				

[1]Scale range: 0-4. [2]Scale range: 0-8. [3]Scale range: 0-12. [4]Scale range: 0-16. [5]Scale range: 0-64

Overall, EiE students responded more positively to the questions about science and engineering jobs on the post-survey than on the pre-survey (JOBS p<.05). Both EiE/test and control students were significantly more likely to say they would enjoy being an engineer on the post-assessment than the pre-assessment (ENGINEER Test p<.001, Control p<.05). There was not a significant difference between EiE and control students for the ENGINEER item; however EiE student gains were larger and more highly significant. In addition, Grade 4 EiE students were more likely to say that they would enjoy being a scientist on their post-survey (SCIENTIST p<.05). On the pre- and post-survey, EiE students were more likely than control students to report that would enjoy being scientist (p<.05).

EiE students were more likely to say that they know about the jobs of scientists and engineers on the post-survey than on the pre-survey (KNOW ABOUT JOBS p<.05). EiE students also were significantly more likely to agree that scientists/engineers make lives better (MAKE LIVES BETTER p<.01), and they were significantly more likely than control students to say so (MAKE LIVES BETTER p<.05).

Both EiE and control students were more likely to say that they like to invent on their post-surveys (INVENT Test p<.05, Control p=.01). Grade 4 EiE students were more likely to say that they like to help society on their post-surveys than their pre-surveys (HELP SOCIETY p<.05).

EiE students were also less likely to agree on the post-survey than the pre-survey that science and math have nothing to do with real life (REAL LIFE p<.05). There was no significant difference between control and test students on the post-survey for this scale, but EiE students were significantly more likely to agree on the pre-assessment than control students (REAL LIFE p<.01).

Engineering Attitudes Survey: Gender

Table 7 compares the responses of male and female EiE (Test) students. Boys responded significantly more positively than girls on the INVENT and ENGINEER scales on both the pre-survey and the post-survey. Though both girls and boys were more likely to say they would enjoy being an engineer on the post-survey (ENGINEER girls p<.05, boys p<.01), girls started and ended less positively than boys. Compared to boys on the post-survey, for example, they were much less likely to show interest in being an engineer (ENGINEER p<.01) or interest in "inventing" and engineering jobs involving cars and infrastructure (INVENT p<.001). Boys were more likely on their post-survey than their pre-survey to show interest in inventing and engineering job involving cars and infrastructure (INVENT p<.05).

Table 7. Engineering Attitudes Survey: Tests for Gender Differences

Question	Within-Group Differences (Pre vs. Post)						Male/Female Differences	
	Female (N=124)			Male (N=96)			PRE	POST
	Pre Mean	Post Mean	p=	Pre Mean	Post Mean	p=	p=	p=
Scale: REAL LIFE[2*]	1.30	0.78	**.003**	1.56	1.08	.136	.594	.269
Scale: CAUSE PROBLEMS[2*]	2.09	2.06	.788	2.66	2.50	.487	.076	.104
Scale: JOBS[5]	34.07	36.23	.079	36.68	38.65	.102	.085	.063
Jobs Factor 1: INVENT[3]	4.55	4.79	.607	6.00	6.81	**.006**	**.000**	**.000**
Jobs F2: HELP SOCIETY[3]	6.66	6.45	.668	5.90	6.08	.754	.062	.403
Jobs F3: FIGURE THINGS OUT[4]	9.44	10.02	.101	10.07	10.32	.898	.178	.563
Jobs F4: MAKE LIVES BETTER[2]	5.60	6.15	**.003**	5.93	6.22	.192	.120	.787
Jobs F5: I KNOW ABOUT JOBS[2]	4.97	5.56	**.009**	5.35	5.47	.440	.190	.634
I'D ENJOY BEING A SCIENTIST[1]	1.65	1.68	.646	1.77	1.67	.408	.538	.913
I'D ENJOY BEING AN ENGINEER[1]	1.29	1.59	**.016**	1.66	2.07	**.004**	**.035**	**.007**

[1]Scale range: 0-4. [2]Scale range: 0-8. [3]Scale range: 0-12. [4]Scale range: 0-16. [5]Scale range: 0-64. *Reversed scale.

Girls on their post-survey were more likely than on their pre-survey to agree that scientists and engineers make people's lives better (MAKE LIVES BETTER $p<.05$) and that they know what scientists and engineers do for their jobs (KNOW ABOUT JOBS $p<.05$). They were also more likely on their post-survey to disagree that science and math have nothing to do with real life (REAL LIFE $p<.05$).

Summary of the Engineering Attitudes Survey Results

Students who completed the EiE curriculum were significantly more likely to agree on the post-survey that scientists and engineers make lives better and that they would enjoy being a scientist than control students. They were also significantly more likely on their post-surveys than their pre-surveys to report that they would enjoy being engineers and to disagree with the statement that science and math have nothing to do with real life.

Girls' and boys' responses overall were significantly different on questions regarding inventing and enjoying being an engineer. Boys showed more interest than girls in the questions having to do with inventing, figuring things out, cars, and structures. 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.

Results for the *Designing Bridges* Unit Questions

In the *Designing Bridges* unit, students use what they have learned in science about forces, balance, and motion to inform their design of a paper bridge. Lesson 1 introduces civil engineering and basic concepts about structures and bridges. Lesson 2 focuses on structures and the forces that act on them. In Lesson 3, students test three bridge designs made of index cards for strength. They use what they have learned from all prior lessons, as well as their science lessons, to design their own bridges in Lesson 4.

The *Designing Bridges* unit assessment was designed and first tested and revised in 2004. Since then it has undergone several revisions to keep pace with changes to the unit and its learning objectives. The version used for the PCET evaluation includes seven questions, one of which is a three-part question asking students to identify three bridge types featured in the unit (question 7).

The questions from the *Designing Bridges* assessment were tested in combination for reliability. Reliability Analysis in SPSS of all questions combined found a Cronbach's $\alpha=.582$, which is lower than the standard coefficient of .7 for acceptable reliability of an instrument. This is probably due to a combination of the low number of response items and the variety of topics covered. Reliability Analysis of the three parts of question 7, however, shows a Cronbach's $\alpha = .765$; student scores on these sub-questions were summed to create a summed scale score with a range of 0-3.

"Designing Bridges" Unit Assessment: Sample Size and Demographic Distribution

The EiE/test sample includes 253 students who completed both a science unit on elementary physics and the EiE unit Designing Bridges between the pre-assessment and post-assessment administrations. The control sample is somewhat larger: 337 students. Control students completed only a science unit on elementary physics after the pre-assessment and before the post-assessment was administered. Both control and test teachers were free to use the science curriculum of their choice to complete the required science instruction during the field/control test period.

Girls made up 49.0% of the control sample and 46.6% of the test sample, a difference which was not significant (Pearson Chi-Square p=.576).

Table 8. *Designing Bridges* Assessment: Sample Size by Grade

		Grade				Total
		2	3	4	5	
Control	Count	90	97	58	92	337
	% of Sample	26.7%	28.8%	17.2%	27.3%	100.0%
Test	Count	46	36	20	151	253
	% of Sample	18.2%	14.2%	7.9%	59.7%	100.0%
Total	Count	136	133	78	243	590
	% of Sample	23.1%	22.5%	13.2%	41.2%	100.0%

Table 9 describes the racial/ethnic distribution of the student population. The majority of both samples was white; minorities made up only 13% of each sample. The difference between the racial/ethnic distributions of the two samples was not significant (Pearson Chi-Square= .205).

Table 9. *Designing Bridges* Assessment: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	8	18	5	270	10	311
	% of sample	2.6%	5.8%	1.6%	86.8%	3.2%	100.0%
Test	Count	7	15	6	188	1	217
	% of sample	3.2%	6.9%	2.8%	86.6%	0.5%	100.0%
Total	Count	15	33	11	458	11	528
	% of sample	2.8%	6.2%	2.1%	86.7%	2.1%	100.0%

"Designing Bridges" Assessment: Questions and Analysis

On the pre- and post-assessments these students were asked questions about bridges, bridge design, and civil engineering. The questions were given to both groups of EiE (test) and control students in grades 2 through 5. Table 10 describes the text for the questions with the correct answers shown in brackets. Students in grades 2-5 received questions 3, 5, 6, and 7. Students in grades 3-5 (not grade 2) received questions 1, 2, and 4.

Most of the assessment questions were completed by approximately 250 EiE test students and 330 control students. Exact sample sizes vary for each question due to the grades tested, as well as individual students skipping some questions on either the pre- or post-assessment.

Table 10. *Designing Bridges* Assessment: Questions (Text)

Question #	Answered by	Question Text
1	Grades 3-5	The car needs to travel along the [span] of the bridge.
2	Grades 3-5	An arch bridge is usually [stronger than] a beam bridge of the same length.
3	Grades 2-5	At work, a civil engineer is MOST likely to [design buildings].
4	Grades 3-5	A highway needs to cross a wide canyon. Civil engineers are designing a bridge to cross the canyon that can hold heavy loads. The canyon is too deep to build supports that reach the water. What kind of bridge would be best to use? [a suspension bridge] *(Figure 2)*
5	Grades 2-5	Mrs. Slater's class has a nature park behind their school with a narrow stream that crosses the path they like to walk on. They want to build a bridge across the stream that is easy to make and not expensive. What kind of bridge would be best for them to build? [a beam bridge]
6	Grades 2-5	Maria placed a board across a stream to make a bridge, but her bridge sagged when she stood on it. What should she do to improve her bridge? [Support the middle] *(Figure 3)*
7 (a-c) (0-3 scale)	Grades 2-5	What kinds of bridges are these? Mark ONE answer for each bridge. (a) [suspension bridge] (b) [arch bridge] (c) [beam bridge] *(Figure 4)*

All questions except questions 7a, 7b, and 7c are reported and analyzed individually. An attempt was made to combine questions into scales; however we found that the questions are generally too distinct to form a reliable scale. The exception is the three items of question 7, asking students to identify types of bridges (Figure 4). These three items were summed into one scale item with Cronbach's $\alpha = .765$ (Reliability Analysis in SPSS). One factor was extracted for the question 7 scale using principal components factor analysis with Varimax rotation, which accounted for 68.1% of the variance.

Table 11 reports results for the analysis of the *Designing Bridges* unit assessment questions. Percent correct on the pre- and post- is reported for each question listed in the left-most column, except the question 7 scale, for which means are reported. Questions 1-6 were analyzed for pre- to post- significant changes (within-group differences) using McNemar's Test of Symmetry for binomial data. Differences between the control and test groups (between-group differences) were tested for significance using the phi coefficient, a χ^2 test. Question 7 was analyzed using the Wilcoxon Signed Ranks Test for within-group differences, and the Wilcoxon Mann-Whitney Test for between-group differences. Exact significance is reported under "p=". P-values significant at p<.05 or below are highlighted in bold.

Question 1 tested students' knowledge of the parts of a bridge. Both EiE and control students were more likely to answer this question correctly on their post-assessments (p<.001). There was no significant difference between test and control students on either the pre- or post-assessment.

Question 2 required students to compare two types of bridges of the same length. Both EiE and control students were more likely to answer this question correctly on their post-assessments (Test p<.001, Control p<.05). There was no significant difference between test and control students on either the pre- or post-assessment.

In Question 3, students identified the work of a civil engineer. Both EiE and control students were more likely to answer this question correctly on their post-assessments (Test p<.001, Control p<.05). In addition, EiE students were more likely to than control students to correctly answer this question on the post-assessment (p<.001).

Table 11. *Designing Bridges* Assessment: Results

		Within-Group Differences (Pre vs. Post)								Test / Control Differences	
		EiE Test				EiE Control				PRE	POST
Q#	**Group**	**N**	**Pre**	**Post**	**p=**	**N**	**Pre**	**Post**	**p=**	**p=**	**p=**
1	Total	186	52.2%	74.2%	**.000**	201	52.2%	72.6%	**.000**	.909	.680
	Grade 2	**Did not complete this question.**									
	Grade 3	36	**N too small to report**			59	**N too small to report**				
	Grade 4	0	**N too small to report**			54	**N too small to report**				
	Grade 5	150	50.7%	70.0%	**.001**	88	62.5%	71.6%	.256	**.048**	.809
2	Total	186	45.7%	71.5%	**.000**	201	54.7%	65.2%	**.046**	.092	.193
	Grade 2	**Did not complete this question.**									
	Grade 3	36	**N too small to report**			59	**N too small to report**				
	Grade 4	0	**N too small to report**			54	**N too small to report**				
	Grade 5	150	46.0%	74.7%	**.000**	88	54.5%	64.8%	.211	.271	.120
3	Total	252	27.4%	50.4%	**.000**	325	27.2%	35.7%	**.019**	.959	**.000**
	Grade 2	46	**N too small to report**			87	13.80%	14.90%	1.000		
	Grade 3	36	**N too small to report**			96	31.20%	40.60%	.233		
	Grade 4	20	**N too small to report**			54	**N too small to report**				
	Grade 5	150	31.30%	51.30%	**.001**	88	37.50%	48.90%	.143	.331	.753
4	Total	184	40.8%	40.2%	1.000	197	32.0%	38.1%	.246	.075	.668
	Grade 2	**Did not complete this question.**									
	Grade 3	36	**N too small to report**			59	**N too small to report**				
	Grade 4	0	**N too small to report**			53	**N too small to report**				
	Grade 5	148	42.6%	43.2%	1.000	85	32.9%	37.6%	.608	.147	.403
5	Total	249	53.0%	64.7%	**.012**	330	46.7%	57.6%	**.006**	.138	.072
	Grade 2	45	**N too small to report**			86	40.7%	40.0%	.268		
	Grade 3	35	**N too small to report**			96	47.9%	60.4%	.104		
	Grade 4	20	**N too small to report**			58	**N too small to report**				
	Grade 5	149	62.4%	59.7%	.724	90	52.2%	62.2%	.262	.137	.762
6	Total	251	70.5%	74.9%	.305	326	67.8%	72.7%	.185	.412	.545
	Grade 2	46	**N too small to report**			86	51.2%	75.6%	**.001**		
	Grade 3	36	**N too small to report**			94	64.9%	66.0%	1.000		
	Grade 4	20	**N too small to report**			56	**N too small to report**				
	Grade 5	149	77.2%	74.5%	.672	90	85.6%	80.0%	.424	.126	.289
7*	Total	248	2.00	2.51	**.000**	324	1.82	2.15	**.000**	.055	**.000**
	Grade 2	45	**N too small to report**			83	1.70	1.81	.303		
	Grade 3	36	**N too small to report**			97	1.85	2.35	**.009**		
	Grade 4	18	**N too small to report**			56	**N too small to report**				
	Grade 5	149	2.09	2.59	**.000**	88	1.91	2.10	.467	.228	**.001**

***Question 7 is a composite scale of questions 7a, 7b, and 7c; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-3) for each student.**

For question 4, (see Figure 2) students selected the best kind of bridge for a situation. There were no significant changes in the responses of test or control students on their post-assessments. There were also no significant differences between test or control students for this question.

Figure 2. ***Designing Bridges*** **Assessment: Question 4**

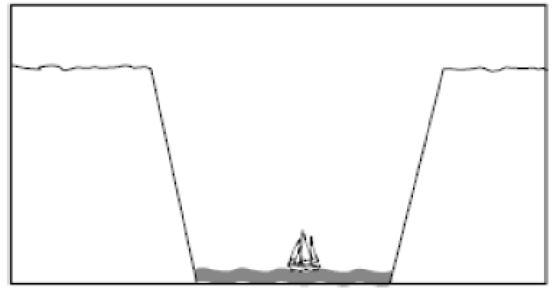
A highway needs to cross a wide canyon. Civil engineers are designing a bridge to cross the canyon that can hold heavy loads. The canyon is too deep to build supports that reach the water. What kind of bridge would be best to use?

Ⓐ a beam bridge

Ⓑ an arch bridge

Ⓒ a suspension bridge

Ⓓ It is not possible to build a bridge.



Question 5 also required students to select the best kind of bridge for a situation. Both EiE and control students were more likely to answer correctly on their post-assessments than on their pre-assessments (Test $p<0.05$, Control $p<.001$). There were no significant differences between these two groups of students.

Question 6 (see Figure 3) required students to determine what to do to improve a bridge. Only grade 2 control students significantly improved on their post-assessments ($p=.001$). There was no significant difference between the EiE and control students' responses for this question.

Figure 3. ***Designing Bridges*** **Assessment: Question 6**

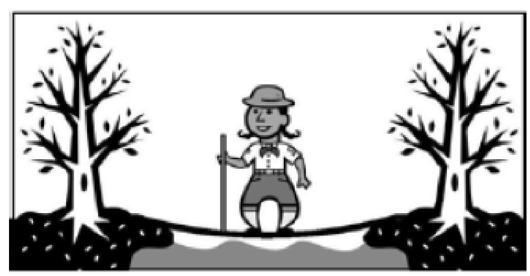
Maria placed a board across a stream to make a bridge, but her bridge sagged when she stood on it. What should she do to improve her bridge?

Ⓐ Support the ends.

Ⓑ Support the middle.

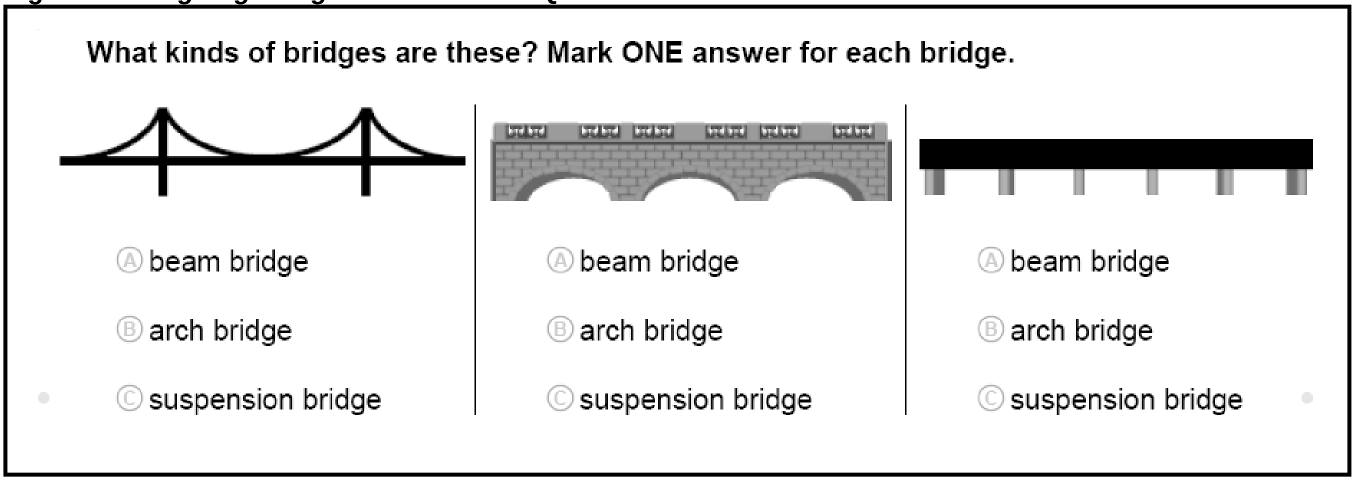
Ⓒ Put some thick cardboard on top.

Ⓓ Put rocks on the ends.



For question 7, students needed to correctly identify different types of bridges. Both EiE and control students improved significantly on this question on their post-assessments ($p<.001$). In addition, EiE students were more likely to correctly answer this question on the post-assessment than the control students ($p<.001$).

Figure 4. *Designing Bridges* Assessment: Question 7



"Designing Bridges" Assessment: Gender Differences

Table 12 shows the gender differences for the *Designing Bridges* assessment. There were no significant differences between boys and girls on any of the questions on the pre- or post-assessment. On their post-assessment, girls were more likely to correctly answer questions 1, 2, 3, and 7 (p<.05). Boys were significantly more likely to correctly answer questions 1, 2, 3, 5, and 7 (p<.05).

Table 12. *Designing Bridges* Assessment: Tests for Gender Differences

	Within-Group Differences (Pre vs. Post)								Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
1	88	55.7%	71.6%	**.044**	96	50.0%	77.1%	**.000**	.441	.393
2	88	40.9%	71.6%	**.000**	96	51.0%	70.8%	**.002**	.168	.910
3	117	27.4%	50.0%	**.001**	135	27.4%	50.4%	**.000**	.992	.953
4	88	40.9%	39.8%	1.000	96	40.6%	40.6%	1.000	.969	.906
5	117	56.4%	67.5%	.155	134	49.3%	62.7%	**.046**	.257	.423
6	117	67.8%	70.9%	.665	135	73.3%	78.4%	.382	.334	.176
7	118	2.04	2.45	**.001**	135	1.97	2.56	**.000**	.612	.291

***Question 5 is a composite scale of questions 5a, 5b, 5c, and 5d; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-4) for each student.**

Summary of the "Designing Bridges" Assessment Results

EiE students were more likely than control students to correctly answer questions in which they identified the type of bridge shown in images. Both EiE and control students significantly improved on post-assessments for several of the *Designing Bridges* assessment questions. However, EiE students improved significantly more than control students on question 3, which asked about the work of civil engineers.

There were no significant differences between boys and girls on any of the questions on their pre- or post-assessments. Both girls and boys were more significantly likely to answer several questions correctly on their post-assessments compared to their pre-assessments.

Results for the *Designing Walls* Unit Questions

Students participating in the *Designing Walls* EiE curriculum unit learn about materials engineering. The unit is designed to be taught in conjunction with a science unit on earth materials. The context of the unit is set by Lesson 1, with a storybook set in China. A young girl and her friend design mortar for constructing a wall around the school garden. Similarly, students' goal in Lesson 4 is to design a mortar that can be used to construct a wall and tested for strength. In Lesson 2, students learn about the different materials that various items are made of. They think about the properties of materials, and how those properties make them more or less appropriate for a variety of uses. In Lesson 3, students experiment with different earth materials to decide which ones work best for use in mortar.

The *Designing Walls* unit assessment was first developed in 2004-2005; it has not been significantly revised since, though the content of the unit has changed. It consists of relatively few questions. Currently this assessment is slated to be revised and tested for validity and reliability in 2009. However, most of the questions on the assessment are still relevant to the unit's content, so we have chosen to report the results regardless.

"Designing Walls" Assessment: Sample Size and Demographic Distribution

Students in grades 2 through 5 participated in the *Designing Walls* field testing and control testing (see Table 13). In all, 508 assessments were analyzed: 231 from control students and 277 from students in EiE classrooms.

Table 13. *Designing Walls* Assessment: Sample Size by Grade, by Control/EiE

		Grade				Total
		2	3	4	5	
Control	Count	41	38	90	62	231
	% of Sample	17.7%	16.5%	39.0%	26.8%	100.0%
Test	Count	106	60	21	90	277
	% of Sample	38.3%	21.7%	7.6%	32.5%	100.0%
Total	Count	147	98	111	152	508
	% of Sample	28.9%	19.3%	21.9%	29.9%	100.0%

Table 14 describes the race/ethnicity of the student population. White students comprised most of the sample (87% of control and 80% of test students). Asian students were 3.6% of the control and 7.9% of the test sample. Hispanic/Latino students and Black students made up less than 7% of each sample.

Table 14. *Designing Walls* Assessment: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	9	8	5	193	6	221
	% of sample	4.1%	3.6%	2.3%	87.3%	2.7%	100.0%
Test	Count	17	24	19	245	0	305
	% of sample	5.6%	7.9%	6.2%	80.3%	.0%	100.0%
Total	Count	26	32	24	438	6	526
	% of sample	4.9%	6.1%	4.6%	83.3%	1.1%	100.0%

Girls and boys each made up approximately half of the sample: girls comprised 50.2% of the control sample, and 49.4% of the EiE (test) sample. The difference was not significant (p=.842).

"Designing Walls" Assessment: Questions and Analysis

On the pre- and post-assessments, students were asked a variety of question about earth materials, the use of materials in technologies, materials engineering, and the engineering design process. Six questions were given to both groups of EiE (test) and control students in grades 3 through 5. Four of these questions—questions 1, 2, 5, and 7—were also given to Grade 2 students. Table 15 describes the text for the questions and displays the correct answer in brackets. Images of questions 7 and 9 from the original assessment are also provided below.

Table 15. *Designing Walls* Assessment: Questions (Text)

Question #	Answered by	Question Text
1	Grades 2-5	Gavin has two rocks. Both are the same kind of rock. What property of his two rocks is MOST likely to be the same? [color]
2	Grades 2-5	Soil is a mixture of many substances. It may include [sand, clay, dead plants, and dead animals].
5 (a-c)* (0-3 scale)	Grades 2-5	Tatiana is making a chair. What would be the BEST material to use if she wants to make a… a. …waterproof chair? [plastic] b. …chair that won't move on windy days? [brick] c. …soft place to sit? [cloth]
6 (a-d)* (0-4 scale)	Grades 3-5	Tom is a materials engineer. Check ALL of the things that Tom would probably do for his job. a. Make a coating for a bike chain that won't rust in the rain. [True] b. Figure out how butterflies hatch. [False] c. Create a bathing suit material that dries quickly. [True] d. Drive a cement truck. [False]
7 (a-d)* (0-4 scale)	Grades 2-5	Some things are made from earth materials. Mark ALL of the things below that are made from earth materials. *(Figure 5)* a. Markers [False b. Basketball [False] c. Road [True] d. Flower pots [True]
9	Grades 3-5	Barry and Carolyn want to make a wall for their pet turtle. They try making a mortar to stick rocks together using clay and water. What should they do before making the wall? [All of the above] *(Figure 6)*

***Questions 5, 6, & 7 are composite scales; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-3 or 0-4 as marked) for each student.**

All of the questions on the *Designing Walls* assessment were scored as correct/incorrect before analysis. Questions 1, 2, and 9 are analyzed and reported as individual items. Differences from pre- to post-assessment were measured for significance using McNemar's Test of Symmetry. Differences between test and control samples on the pre-assessment and on the post-assessment were measured for significance using the phi coefficient.

Questions 5, 6, and 7 are actually composite scales for items with multiple sub-questions. All of these scales were tested using Reliability Analysis in SPSS; none met the reliability threshold of Cronbach's $\alpha = .7$; however for ease of interpretation they were analyzed as scales regardless. Future work is planned to revise this assessment to increase reliability. Question 5 is a three-part question comprising a 0-3 scale (Cronbach's $\alpha = .558$): 1 point for each correct answer. Questions 6 and 7 are four-part questions; 1 point for each correct answer sums to a 0-4 point scale for each. Cronbach's $\alpha = .496$ for question 6, and Cronbach's $\alpha = .314$ for question 7. Student responses on these scales were found to be non-normally distributed using the Shapiro-Wilk test in SPSS; therefore differences from pre- to post-assessment were analyzed using the Wilcoxon Signed Ranks test for dependent variables, and differences between the control and test groups were analyzed using the Wilcoxon Mann-Whitney Test for independent variables.

Table 16 includes the assessment question results for EiE test and Control samples. For questions 1, 2, and 9, the percentage correct on the pre-assessment and on the post-assessment is given for each sample, test and control. For questions 5, 6, and 7, the mean is instead given for each assessment. The sample sizes are given in the columns marked "N". Sample sizes are smaller for questions 6 and 9 because these items were not given to grade 2 students. Significance tests of the dependent variables (pre- vs. post-assessment) are given for each sample, test and control. Significance tests of the independent variables (test vs. control) are given in the rightmost two columns.

Table 16. *Designing Walls* Assessment: Results

	Within-Group Differences (Pre vs. Post)								Test / Control Differences	
	EiE Test				EiE Control				PRE	POST
Question #	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
1	216	60.2%	65.3%	0.334	231	58.9%	65.4%	0.195	0.778	0.984
2	218	41.7%	50.0%	0.108	227	24.7%	46.7%	**0.000**	**0.000**	0.486
5_scale* (0-3)	256	2.02	2.63	**0.000**	229	2.56	2.62	0.320	**0.000**	0.902
6_scale* (0-4)	135	3.38	3.68	**0.003**	162	3.23	3.25	0.783	0.206	**0.000**
7_scale* (0-4)	264	3.25	3.31	0.343	231	3.14	3.17	0.605	0.083	**0.038**
9	135	40.7%	78.5%	**0.000**	162	63.6%	59.3%	0.494	**0.000**	**0.000**

***Questions 5, 6, & 7 are composite scales; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-3 or 0-4 as marked) for each student.**

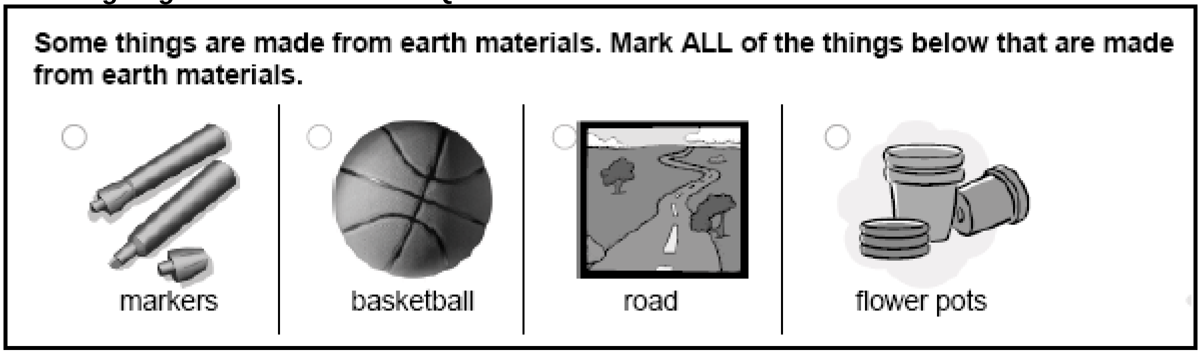
No differences were found between the test and control groups on question 1, a science question about rocks; nor did either group improve significantly on this question. It may be that this was not a good match to the tie-in science content of this unit, which is more about clay and sand than about rocks. The control group improved on question 2 while the test group did not; however this was due to a significant difference on the pre-assessment, so no attributions can be made about the EiE curriculum. It is possible that some teachers in the test sample gave their assessments mid-way through their science units; it was not possible to confirm science teaching dates for all classrooms during this study.

EiE students improved significantly on question 5 between the pre- and post-assessment, while control students did not. Again, however, the only difference between test and control was on the pre-assessment. While the test group improvement may have been due to the EiE curriculum, it is also possibly due to some other factor.

On question 6, EiE students improved significantly while control students did not. This question asked what a materials engineer might do for his/her job. Both groups performed similarly on the pre-assessment; however, EiE student performance was significantly better than control on the post-assessment. In this case, it is more likely that the improvement is attributable to the EiE curriculum.

Question 7 asked which of four technologies are made from earth materials (see Figure 5). EiE students did significantly better than control students on the post-assessment but not on the pre-assessment. However, neither group's improvement on this question was significant, though the EiE improvement was slightly larger in magnitude.

Figure 5. ***Designing Walls*** **Assessment: Question 7**



For question 9, students were asked about what they should do before making a wall (see Figure 6). The steps of the engineering design process are an important part of every EiE unit; this question measures students' understanding of the steps of the process. EiE students did significantly worse than control on the pre-assessment, but significantly better on the post-assessment. EiE students improved significantly, while control students did not.

Figure 6. ***Designing Walls*** **Assessment: Question 9**

Barry and Carolyn want to make a wall for their pet turtle. They try making a mortar to stick rocks together using clay and water. What should they do before making the wall?

Ⓐ Test the mortar.

Ⓑ Decide how much clay and water they will need.

Ⓒ Make a plan for where to put the rocks.

Ⓓ all of the above

"Designing Walls" Assessment: Gender Differences

Table 17 shows that there were no gender differences on either the pre- or the post-assessment. Female students improved significantly on two questions (5 and 9), while males improved on three (5, 6, and 9).

Table 17. ***Designing Walls*** **Assessment: Tests for Gender Differences**

	Within-Group Differences (Pre vs. Post)								Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
1	107	57.0%	70.1%	.302	109	63.3%	60.6%	1.000	.345	.141
2	108	38.9%	50.9%	.672	110	44.5%	49.1%	.771	.397	.786
5*	128	2.11	2.59	**.000**	130	2.06	2.68	**.000**	.833	.312
6*	75	3.33	3.56	.199	66	3.32	3.68	**.003**	.989	.461
7*	131	3.21	3.37	.093	133	3.30	3.30	.725	.284	.571
9	74	44.6%	77.0%	**.000**	61	36.1%	80.3%	**.000**	.316	.642

***Questions 5, 6, & 7 are composite scales; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-3 or 0-4 as marked) for each student.**

Summary of the "Designing Walls" Assessment Results

This assessment was composed of relatively few questions which were not as well matched to the unit's learning objectives as more recently constructed EiE assessments. However, EiE students showed significant improvement on at least three questions, which is most likely due to participation in the EiE curriculum. Two of these questions ask about the materials that technologies are made of, or could be made of. The third asks about the engineering design process. Even with a fairly small sample size, students showed improvement on these questions. The performance of girls and boys was essentially identical.

Results for the *Designing Windmills* Unit Questions

In the EiE curriculum unit *Designing Windmills*, students are introduced to the field of mechanical engineering and how machines designed by mechanical engineers are integral to the utilization of wind energy as a renewable energy source. Students examine and diagram the workings of several common machines such as mechanical pencils, egg beaters, and rolling pins (Lesson 2). Students then investigate the different materials and shapes conducive to catching the wind, first by designing sails for small boats (Lesson 3) and ultimately by designing their own windmill blades (Lesson 4). During the course of the lessons, students learn about wind turbines; machines designed by mechanical engineers that act as a renewable energy source in countries around the world.

The *Designing Windmills* assessment was designed and first tested during the 2005-2006 school year. It was revised during the 2006-2007 school year, when a number of questions were dropped or revised. The assessment was again administered to students during the 2007-2008 school year.

"Designing Windmills" Unit Assessment: Sample Size and Demographic Distribution

The test sample included 411 students who completed both a science unit on weather and the EiE unit *Designing Windmills* between the pre-assessment and post-assessment administrations. There were 271 control students whom completed only a science unit on weather after the pre-assessment and before the post-assessment was administered. Table 18 describes the distribution of students in both samples by grade. Both control and test teachers were free to use whatever science curriculum they wished to complete the required weather science instruction during the field test period.

Table 18. *Designing Windmills* Assessment: Sample Size by Grade

		Grade				Total
		2	3	4	5	
Control	Count	19	29	93	159	300
	% of Sample	6.3%	9.7%	31.0%	53.0%	100.0%
Test	Count	51	35	78	259	423
	% of Sample	12.1%	8.3%	18.4%	61.2%	100.0%
Total	Count	70	64	171	418	723
	% of Sample	9.7%	8.9%	23.7%	57.8%	100.0%

Girls made up 49.8% of the control sample and 50.2% of the test sample, a difference which was not significant (Pearson Chi-Square p=.924).

Table 19 describes the racial/ethnic distribution of the student population. White students made up the majority of both the control and test samples. Asian students made up the second largest population within each sample – 12.9% of the control sample, and 10.7% of the test sample. The test sample was 3.0% Black and 2.0% Hispanic, while the control sample was 3.0 % Black and 3.0% Hispanic. Too few students comprised the different ethnic groups for both the test and control samples, so race/ethnicity test results are not reported.

Table 19. *Designing Windmills* Assessment: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	8	35	8	217	3	271
	% of sample	3.0%	12.9%	3.0%	80.1%	1.1%	100.0%
Test	Count	12	43	8	334	6	403
	% of sample	3.0%	10.7%	2.0%	82.9%	1.5%	100.0%
Total	Count	20	78	16	551	9	674
	% of sample	3.0%	11.6%	2.4%	81.8%	1.3%	100.0%

"Designing Windmills" Assessment Questions and Analysis

On the pre- and post-assessments students were asked questions about the wind and weather, the field of mechanical engineering, and the materials and properties of windmills and other similar machines. The questions were given to both groups of EiE (test) and control students in grades 2 through 5. Table 20 describes the text for the questions with the correct answer shown in brackets. Students in grades 3 through 5 received questions all questions, while grade 2 students only received questions 4a, 4b, 4c, 4d, 5, and 6.

Questions 1, 4a, 4b, 4c, 4d, 5, and 6 are reported and analyzed individually. The six items of question 7 were summed into one scale item with Cronbach's α =.800 (Reliability Analysis in SPSS). The six items of question 8 were also summed into one scale item (Cronbach's α =.865). Additionally, all items administered to grades 3-5 students were summed into the 'All' scale item (Cronbach's α =.747).

Significant changes from the pre-assessment to the post-assessment (within-group differences) were analyzed for individually reported items using McNemar's Test of Symmetry. Between-group differences (test vs. control) were analyzed using the phi coefficient. The scales representing questions 7, 8, and all items were analyzed using nonparametric statistics, since the data was not normally distributed.

Table 20. *Designing Windmills* Assessment: Questions (Text)

Question #	Answered by	Text of component questions
1	Grades 3-5	Which of the following does NOT show how hard the wind is blowing? [a weather vane]
4 (a-d)	Grades 2-5	Shara is making a windmill, but cannot make it spin. She makes the blades bigger, but it still does not spin. Mark ALL of the things that she might do next to improve her windmill. a. Add more blades [True] b. Put holes in the blades to let air through [False] c. Change the materials the blades are made of [True] d. Change the angle of the blades [True]
5	Grades 2-5	Windmills and sailboats: [use wind energy]
6	Grades 2-5	Jamal is a mechanical engineer. For his job, Jamal might: [improve machines]
7 (a-f) (0-6 scale)	Grades 3-5	Which of these machines do the same kind of work (cutting) as a pair of scissors? (Figure 7) a. pliers [False] b. garden shears [True] c. kitchen knife [True] d. vegetable peeler [True] e. hair curling iron [False] f. tongs [False]
8 (a-f) (0-6 scale)	Grades 3-5	Which of these machines have parts that you would move in the same way as a pair of scissors? (*Figure 8*) a. pliers [False] b. garden shears [True] c. kitchen knife [True] d. vegetable peeler [True] e. hair curling iron [False] f. tongs [False]
All (0-19 scale)	Grades 3-5	*Summation of all items from the* Designing Windmills *Assessment*

Table 21 reports for the analysis of the *Designing Windmills* unit assessment. Percent correct on the pre- and post- is reported for each question listed in the left-most column except the scale items for questions 7 and 8 as well as the summation of all items. Instead, means are reported for these scale items. For the within-groups analysis, McNemar's chi-square was used to test significance for the binary values (all but the scale items). Because questions 7, 8, and 'All' proved to be non-normally distributed, significance of each of these scales was tested using the nonparametric Wilcoxon Signed Ranks Test. The chi-square phi statistic was used to test for significant differences between the control and test groups for all questions except the scale items, for which we used the Wilcoxon Mann-Whitney Test.

For all questions, the numbers of students in grades 2 and 3 for the control and test samples are included. Grades 2 and 3 students are included in the overall results for each question, however results are not reported for students in grades 2 and 3 individually because they did not make up a large enough portion of either sample.

Question 1 asks students to choose which items among a weather vane, clouds, an anemometer, and trees does not show how hard the wind blows (answer: weather vane). The question was administered to control and test students in grades 3-5 only. EiE (test) students improved significantly on the question overall ($p<.001$) and in grade 5 ($p<.001$). Control students also improved overall ($p<.001$) and in grade 5 ($p<.001$). There were no significant between-group differences overall or for a specific grade on either the pre- or post-assessment.

Table 21*. Designing Windmills* Assessment: Results

		Within-Group Differences (Pre vs. Post)								Test / Control Differences	
		EiE Test				EiE Control				PRE	POST
Q#	Group	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
1	Total	478	16.5%	37.3%	**.000**	278	13.3%	32.7%	**.000**	.237	.226
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	65	10.8%	15.4%	.629	62	8.1%	19.4%	.092	.602	.555
	Grade 5	258	15.9%	48.4%	**.000**	156	17.3%	41.7%	**.000**	.706	.206
4a	Total	533	27.8%	54.8%	**.000**	300	20.7%	23.6%	.320	**.023**	**.000**
	Grade 2	51	**N too small to report**			19	**N too small to report**				
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	37.9%	30.3%	.473	64	14.1%	31.2%	**.035**	**.002**	.907
	Grade 5	259	21.6%	61.8%	**.000**	159	20.8%	22.6%	.755	.834	**.000**
4b	Total	533	67.4%	86.9%	**.000**	300	69.0%	72.9%	.076	.625	**.000**
	Grade 2	51	**N too small to report**			19	**N too small to report**				
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	57.6%	78.8%	**.009**	64	70.3%	78.1%	.332	.131	.927
	Grade 5	259	72.2%	91.5%	**.000**	159	70.4%	74.8%	.337	.699	**.000**
4c	Total	533	70.5%	85.5%	**.000**	300	61.7%	66.8%	.128	**.009**	**.000**
	Grade 2	51	**N too small to report**			19	**N too small to report**				
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	72.7%	72.7%	1.000	64	53.1%	56.2%	.832	**.021**	**.049**
	Grade 5	259	69.5%	88.0%	**.000**	159	69.2%	76.7%	.111	.946	**.002**
4d	Total	533	78.6%	91.2%	**.000**	300	69.7%	70.4%	.576	**.004**	**.000**
	Grade 2	51	**N too small to report**			19	**N too small to report**				
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	71.2%	83.3%	.134	64	73.4%	71.9%	1.000	.777	.117
	Grade 5	259	80.3%	93.8%	**.000**	159	82.4%	75.5%	.117	.598	**.000**
5	Total	525	81.1%	94.3%	**.000**	296	80.1%	82.0%	.419	.707	**.000**
	Grade 2	50	**N too small to report**			18	**N too small to report**				
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	60	66.7%	95.0%	**.000**	63	79.4%	71.4%	.359	.112	**.001**
	Grade 5	258	87.6%	95.7%	**.001**	157	83.4%	91.7%	**.011**	.236	.089
6	Total	517	77.2%	84.8%	**.005**	280	72.9%	75.8%	.124	.175	**.003**
	Grade 2	51	**N too small to report**			18	**N too small to report**				
	Grade 3	35	**N too small to report**			28	**N too small to report**				
	Grade 4	57	73.7%	80.7%	.523	55	80.0%	72.7%	.454	.429	.318
	Grade 5	251	78.5%	87.6%	**.004**	140	73.6%	85.0%	**.007**	.270	.460
7*	Total	411	3.30	4.04	**.000**	271	4.16	4.28	.077	**.000**	.155
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	2.45	4.24	**.000**	64	4.19	4.56	**.033**	**.000**	.157
	Grade 5	259	4.09	4.74	**.000**	159	4.75	4.75	.827	**.000**	.712
8*	Total	411	3.71	4.57	**.000**	271	4.20	4.48	**.000**	**.044**	**.012**
	Grade 3	35	**N too small to report**			29	**N too small to report**				
	Grade 4	66	3.05	4.79	**.000**	64	4.22	4.78	**.005**	**.026**	.471
	Grade 5	259	4.49	5.37	**.000**	159	4.87	5.08	**.043**	.160	**.002**
All*	Total	347	12.46	15.22	**.000**	234	12.79	13.66	**.000**	.991	**.000**
	Grade 2	**Did not complete all questions.**									
	Grade 3	35	**N too small to report**			28	**N too small to report**				
	Grade 4	57	10.33	13.59	**.000**	62	12.18	13.11	**.007**	.103	.694
	Grade 5	255	12.89	15.77	**.000**	144	13.67	14.53	**.000**	.059	**.000**

***Questions 7, 8 and All are composite scales which report means instead of % correct. The means are calculated from the sum of correct responses for each student. Questions 7 and 8 each range from 0-6 and All ranges from 0-19.**

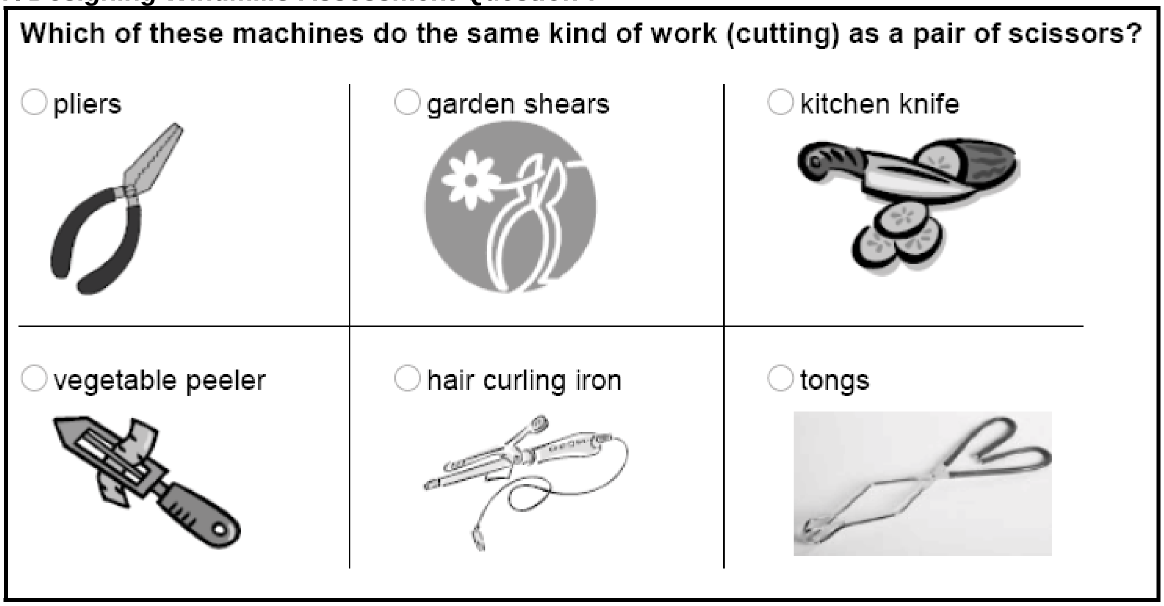
All four items of question 4a-d ask students the same question - to determine whether an answer choice would improve a windmill that has non-spinning blades. Choices 4a (add blades), 4c (change blades' materials), and 4d (change blades' angles) would all improve the windmill, while 4b (put holes in the blades) would not. The questions were administered to students in grades 2 through 5. EiE (test) students improved significantly overall for questions 4a (p<.001), 4b (p<.001), 4c (p<.001), and 4d (p<.001). Test students in grade 4 improved significantly for question 4b (p<.01). Test students in grade 5 improved significantly on 4a (p<.001), 4b (p<.001), 4c (p<.001), and 4d (p<.001). Control students overall did not improve significantly on any of the question 4 items, however control students in grade 4 did improve significantly on question 4a (p<.05). Between groups on the pre-assessment overall, EiE students answered significantly differently than control students on questions 4a (p<.05), 4c (p<.01), and 4d (p<.01). In grade 4, the two groups also differed significantly on pre-assessment for questions 4a (p<.01) and 4c (p<.05). Between groups on the post-assessment, EiE students did significantly better than control students overall on questions 4a, 4b, 4c, and 4d (p<.001). For grade 4, EiE students did significantly better on question 4c (p<.05). For grade 5, test students outperformed control students on the post-assessment on questions 4a (p<.001), 4b (p<.001), 4c (p<.01), and 4d (p<.001). Based on these results, EiE students overall improved significantly more than control students overall on question 4b. EiE student improvement was greater than control on all question 4 sub-items, and significantly better than control on the post-assessment for all question 4 sub-items.

Question 5 asks students to choose the best descriptor for windmills and sailboats, with the choices being 'make wind', 'use wind energy', 'use solar energy', and 'don't need energy to move' (answer: use wind energy). Students in grades 2 through 5 were given this question. EiE (test) students showed significant improvement overall (p<.001) and in grade 4 (p<.001) and grade 5 (p=.001). Control students improved overall (p<.001) and for grade 4 (p=.001) only. Between the two samples, EiE students did significantly better than control students on the post-assessment overall (p<.001) and in grade 4 (p=.001). Since the two groups did not differ significantly on the pre-assessment, test students improved significantly more than control, overall and in grade 4.

Question 6 asks students to identify what Jamal, a mechanical engineer, may do for his job. The choices are 'install wiring in houses', 'repair bicycles', 'predict the weather', and 'improve machines' (answer: improve machines). EiE (test) students did improve significantly overall (p<.01) and in grade 5 (p<.01). Control students only improved significantly in grade 5 (p<.01). Between groups, EiE students did significantly better than control students on the post-assessment overall (p<.01). Since there was no significant difference between groups on the pre-assessment overall, EiE students overall improved significantly more than control students.

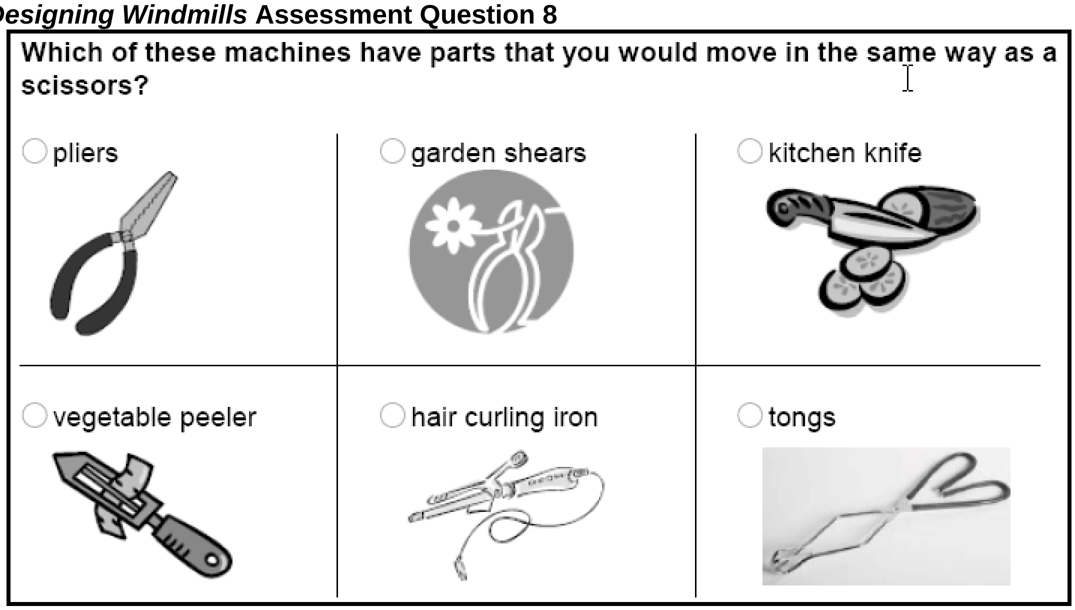
The question 7 scale, administered to students in grades 3 through 5, asks students to identify which of six machines does the same kind of work (cutting) as scissors. EiE (test) students improved significantly overall (p<.001) as well as in grades 4 and 5 (p<.001). Control students only improved significantly in grade 4 (p<.05). Between groups, test and control students differed significantly on the pre-assessment overall (p<.001), in grade 4 (p<.001), and grade 5 (p<.001). The groups did not differ significantly on the post-assessment.

Figure 7. ***Designing Windmills*** **Assessment Question 7**



The question 8 scale asks students to identify if the same six machines have parts that move in the same way as scissors. It was administered to students in grades 3 through 5. EiE (test) students improved significantly overall (p<.001), in grade 4 (p<.001), and in grade 5 (p<.001). Control students also improved significantly overall (p<.001), in grade 4 (p=.005), and in grade 5 (p=.043). Between groups, test and control students performed significantly differently overall (p<.05) and in grade 4 (p<.05). On the post-assessment, EiE students did significantly better than control students overall (p<.05) and in grade 5 (p<.01).

Figure 8. ***Designing Windmills*** **Assessment Question 8**



The 'All' item scale only includes students in grades 3 through 5 because it is the summation of all *Designing Windmills* assessment questions, including those not administered to grade 2 students. EiE (test) students improved significantly overall (p<.001), in grade 4 (p<.001), and in grade 5 (p<.001). Control students also improved significantly overall (p<.001), in grade 4 (p<.01), and in grade 5 (p<.001). Based on this and the mean values reported, EiE students improved by significantly larger margins than control students overall as well as in grades 4 and 5. Test students also performed significantly better than control students on the post-assessment overall (p<.001) and in grade 5 (p<.001).

"Designing Windmills" Assessment: Gender Differences

Table 5 shows the gender differences for the *Designing Windmills* assessment. Males scored significantly higher than females on the pre-assessment for questions 1 (p<.01) and 6 (p=.017). But there were no significant gender differences on any other pre-assessment questions or any questions on the post-assessment. Females did improve significantly on all questions. Males improved significantly on all questions except 6 (p=.880).

Table 22. *Designing Windmills* Assessment: Tests for Gender Differences (Test Students Only)

Within-Group Differences (Pre vs. Post)									Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
1	179	10.1%	35.8%	**.000**	179	20.1%	42.5%	**.000**	**.008**	.194
4a	209	27.3%	55.0%	**.000**	202	26.7%	54.0%	**.000**	.902	.829
4b	209	63.6%	87.1%	**.000**	202	70.3%	86.6%	**.000**	.151	.893
4c	209	74.2%	87.1%	**.001**	202	69.8%	83.2%	**.000**	.325	.265
4d	209	78.9%	91.4%	**.001**	202	78.2%	91.1%	**.000**	.857	.915
5	202	77.7%	93.1%	**.000**	201	84.1%	96.0%	**.000**	.105	.192
6	198	73.2%	86.9%	**.000**	196	83.2%	84.2%	.880	**.017**	.449
7*	209	3.18	3.99	**.000**	202	3.42	4.10	**.000**	.261	.709
8*	209	3.67	4.54	**.000**	202	3.75	4.61	**.000**	.727	.576
All*	165	12.33	15.4	**.000**	174	12.54	15.08	**.000**	.935	.434

***Questions 7, 8 and All are composite scales which report means instead of % correct. The means are calculated from the sum of correct responses for each student. Questions 7 and 8 each range from 0-6 and All ranges from 0-19.**

Summary of the "Designing Windmills" Assessment Results

EiE (test) students performed significantly better on the post-assessment than control students on most questions. This difference was particularly dramatic for students in grade 5. EiE students overall did significantly better on the post-assessment than control students on the 'All' scale item, which is the summation of performance on all items administered to students in grades 3 through 5. EiE students also showed significantly more improvement from the pre- to the post-assessment. On the technology and engineering questions especially—questions about what mechanical engineers do for their jobs, how to improve windmills, and technologies that use wind energy—the EiE students improved significantly from pre- to post-assessment, while control students did not; their performance was significantly better than control on the post-assessment. Results for the science questions are less clear, though EiE students did slightly (if not always significantly) better than control on all of those questions as well.

The performance of boys and girls was not significantly different on the pre-assessment for almost all questions. There were no significant performance differences between genders on the post-assessment at all. Both girls and boys showed significant improvement from the pre- to the post-assessment.

Results for the *Making Work Easier* Unit Questions

In the EiE curriculum unit *Making Work Easier*, students are introduced to the field of industrial engineering. They learn about the use of simple machines in factory subsystems, as well as about technological processes and basic ergonomics. In Lesson 2, students learn about industrial processes as they work to construct folders first on their own and then in assembly lines. The class compares how many folders they made using the two methods and discusses the advantages and disadvantages of each. In Lesson 3, students have the opportunity to test several different types of simple machines to become familiar with them and learn how they make work easier. Through both quantitative and qualitative measurements and observations, students learn more about how these different simple machines reduce the amount of force and/or change the direction of the force needed to move a load. Lesson 4 is a chance for students to apply what they have learned about simple machines, processes, the concept and measurement of force, and ergonomics to improve a factory subsystem.

The *Making Work Easier* assessment was designed and first tested during Year 2 of the EiE project (the 2004-2005 school year). It was revised during 2006-2007, when a number of questions were dropped or revised. The assessment was administered to PCET control students during the 2006-2007 school year, and to PCET field test students during the 2007-2008 school year—Year 5 of the EiE project.

"Making Work Easier" Unit Assessment: Sample Size and Demographic Distribution

The sample includes 1299 students. Of these, 917 students (the test sample) completed both a science unit on simple machines and the EiE unit *Making Work Easier* between the pre-assessment and post-assessment administrations. Control students completed only a science unit on simple machines after the pre-assessment and before the post-assessment was administered; these students numbered 382. Both control and test teachers were free to any science curriculum they wished to complete the simple machines science instruction during the field test period.

Girls made up 49.5% of the control sample and 48.7% of the test sample. Of 1136 students for whom information was provided, 77 (6.8%) received free or reduced-price lunch from the National School Lunch Program.

Students in grades 2-5 were assessed, as well as a very small number of grade 6 students. Due to the small number of grade 6 students, results for this grade level are not reported in this paper.

Table 23 describes the racial/ethnic distribution of the student population. White students made up the majority of both the control and test samples—approximately 90% of each sample. Asian students made up a distant second largest population within each sample, 4.2% of the population overall.

Table 23. *Making Work Easier* Assessment: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	6	28	7	331	4	376
	% of sample	1.6%	7.4%	1.9%	88.0%	1.1%	100.0%
Test	Count	35	25	15	802	13	890
	% of sample	3.9%	2.8%	1.7%	90.1%	1.5%	100.0%
Total	Count	41	53	22	1133	17	1266
	% of sample	3.2%	4.2%	1.7%	89.5%	1.3%	100%

"Making Work Easier" Assessment: Questions and Analysis

On the pre- and post-assessments these students were asked questions about simple machines, forces, and industrial engineering. The questions included science questions about simple machines and forces. Students were also asked about technology. One question pertained to improving processes, which relates to the work of industrial engineers.

The questions were given to both groups of EiE (test) and control students in grades 2 through 6. Table 10 describes the text for the questions with the correct answer shown in brackets. Students in grades 3-6 received questions 3, 5, 9, and 10, while students in grade 2 received questions 6, 7, and 14.

Most of the assessment questions were completed by approximately 900 EiE test students and 230-380 control students, depending on the question. Exact sample sizes vary for each question due to the grades tested and individual students skipping some questions on either the pre- or post-assessment.

Table 24. *Making Work Easier* Assessment: Questions (Text)

Question #	Answered by	Question Text
3	Grades 3-6	The diagrams below represent the position of a balance with weights on it. All the weights are the same. Which diagram is NOT correct? [balance left of center; 1 weight on left; 2 weights on right] (*Figure 9*)
5	Grades 3-6	Rich is using a rope and pulley to lift a weight. Choose the arrow that shows the direction in which he is applying force to the [*arrow pointing down*] (*Figure 10*)
6	Grades 2-6	Which of the following is technology? [all of the above (a way to make air clean, a computer, a method for putting together wheelchairs)]
7	Grades 2-6	Which technology would NOT decrease the force needed to move the box? [fixed single pulley] (*Figure 11*)
9	Grades 3-6	Alex tested this lever to lift his books. The force required to lift the books was 7 Newtons. He then improved his lever to make it easier to lift his books. The force required to lift the books the same height will now be: [less than 7 Newtons] (*Figure 12*)
10 (a-d)	Grades 3-6	Industrial engineers often work to improve processes. Mark ALL the processes in the list below. a. assembling a backpack [Yes] b. a backpack [No] c. a double pulley [No] d. baking cookies [Yes]
14 (a-f) (0-6 scale)	Grades 2-6	Look at each picture. Mark the simple machine shown in each picture. (*Figure 13*) a. skateboard [wheel and axle] b. top of flagpole [pulley] c. ladder [inclined plane] d. thumb tack [wedge] e. pliers [lever] f. jelly jar with lid [screw]

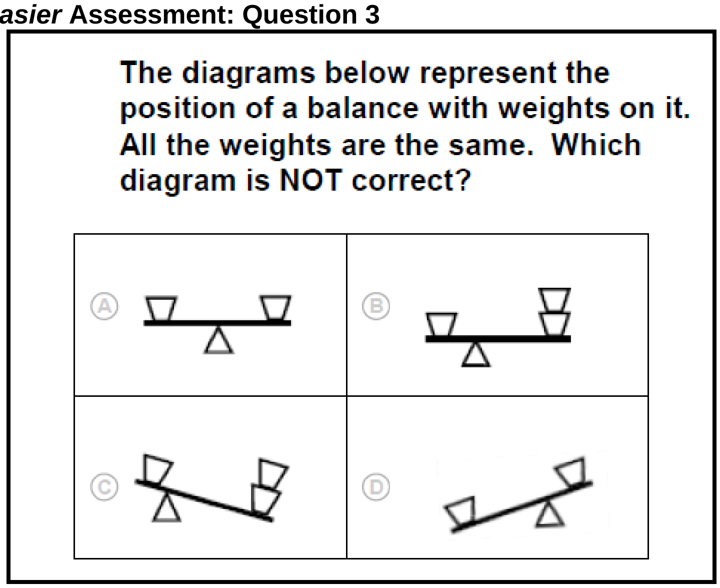
All questions except question 14 are reported and analyzed individually. An attempt was made to combine questions into scales; however we found that the questions are generally too distinct to form a reliable scale. The exception is the six items of question 14, asking students to identify the type of simple machine represented an item shown in a drawing. These six items were summed into one scale item with Cronbach's $\alpha = 0.617$ (Reliability Analysis in SPSS).

Significant changes from the pre-assessment to the post-assessment (within-group differences) were analyzed for individually reported items using McNemar's Test of Symmetry. Between-group differences (test vs. control) were analyzed using the phi coefficient. The question 14 scale was analyzed using nonparametric statistics, since the data were not normally distributed.

Table 11 reports results for the analysis of the *Making Work Easier* unit assessment questions. Percent correct on the pre- and post- is reported for each question listed in the left-most column, except the question 14 scale, for which means are reported. For the within-groups analysis, McNemar's chi-square was used to test significance for the binary values (all but the question 14 scale). Because question 14 proved to be non-normally distributed, significance of the question 14 scale was tested using the nonparametric Wilcoxon Signed Ranks Test. The chi-square phi statistic was used to test for significant differences between the control and test groups for all questions except the question 14 scale, for which we used the Wilcoxon Mann-Whitney Test.

Question 3 (see Figure 9) requires students to recognize which balance diagram is not correct. On the pre-assessment, control students scored significantly better than EiE test students overall and than the grade 4 students ($p<.05$). EiE test students overall improved significantly on this question from pre- to post-assessments ($p<.001$), including students in grades 4 ($p<.05$) and grade 5 ($p<.001$). Grade 3 students did not improve significantly on this question. Control students did not improve significantly on the post-assessment.

Figure 9. *Making Work Easier* Assessment: Question 3



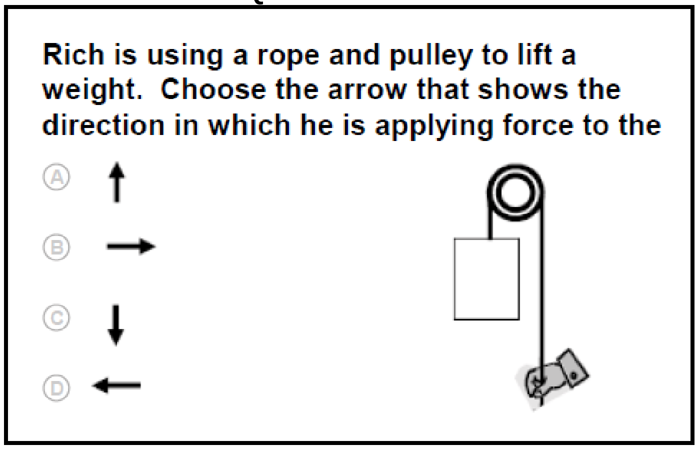
Question 5 (see Figure 10) tests students' ability to recognize the direction of a force that has been applied in the image shown in Figure 11. Test students improved significantly ($p=.001$) on this question, while control students did significantly worse on the question ($p<.05$). Both EiE test students in grade 3 and grade 5 were subgroups that improved significantly ($p<.05$). For grade 4, EiE test students improved, but not significantly, and control students decreased significantly ($p<.05$). On the post-assessment, grade 4 students performed significantly better than grade 4 control students ($p<.05$).

Table 25. *Making Work Easier* Assessment: Results

		Within-Group Differences (Pre vs. Post)								Test / Control Differences	
		EiE Test				EiE Control				PRE	POST
Q#	**Group**	**N**	**Pre**	**Post**	**p=**	**N**	**Pre**	**Post**	**p=**	**p=**	**p=**
3	Total	896	56.3%	67.2%	**.000**	233	63.5%	67.1%	.328	**.045**	.981
	Grade 3	98	50.0%	58.2%	.324	0	**N too small to report**				
	Grade 4	174	50.0%	65.7%	**.002**	120	62.5%	65.3%	.743	**.034**	.935
	Grade 5	593	58.2%	68.7%	**.000**	113	64.6%	69.0%	.362	.203	.948
5	Total	906	87.4%	91.9%	**.001**	236	94.5%	88.9%	**.035**	**.002**	.156
	Grade 3	100	71.0%	86.9%	**.005**	0	**N too small to report**				
	Grade 4	172	88.4%	90.3%	.711	121	94.2%	82.4%	**.004**	.089	**.047**
	Grade 5	603	89.4%	92.9%	**.020**	115	94.8%	95.7%	1.000	.074	.268
6	Total	939	36.0%	63.0%	**.000**	381	30.2%	37.2%	**.008**	**.044**	**.000**
	Grade 2	35	**N too small to report**			144	11.8%	13.0%	.839		
	Grade 3	99	11.1%	65.6%	**.000**	0	**N too small to report**				
	Grade 4	176	14.8%	47.7%	**.000**	121	38.0%	48.3%	.058	**.000**	.923
	Grade 5	598	46.8%	67.4%	**.000**	116	44.8%	56.5%	.053	.693	**.025**
7	Total	940	21.9%	30.5%	**.000**	380	26.1%	26.3%	1.000	.106	.124
	Grade 2	32	**N too small to report**			145	23.4%	25.9%	1.000		
	Grade 3	100	14.0%	52.0%	**.000**	0	**N too small to report**				
	Grade 4	177	19.2%	35.8%	**.000**	121	31.4%	20.2%	.066	**.016**	**.004**
	Grade 5	600	23.7%	26.5%	.257	114	23.7%	33.0%	.144	.997	.150
9	Total	905	36.1%	59.9%	**.000**	236	45.8%	45.7%	1.000	**.007**	**.000**
	Grade 3	100	20.0%	66.7%	**.000**	0	**N too small to report**				
	Grade 4	175	25.1%	44.6%	**.000**	121	43.0%	49.6%	.291	**.001**	.398
	Grade 5	599	41.9%	63.5%	**.000**	115	48.7%	41.7%	.256	.178	**.000**
10a	Total	913	71.7%	78.8%	**.000**	237	75.9%	75.5%	1.000	.196	.285
	Grade 3	100	53.0%	76.0%	**.001**	0	**N too small to report**				
	Grade 4	177	66.1%	83.6%	**.000**	121	79.3%	74.4%	.392	**.013**	.051
	Grade 5	464	23.3%	78.0%	.619	116	72.4%	76.7%	.511	.323	.759
10b	Total	913	73.9%	75.2%	.688	237	75.1%	79.3%	.289	.713	.190
	Grade 3	100	77.0%	76.0%	1.000	0	**N too small to report**				
	Grade 4	177	76.8%	84.2%	.085	121	80.2%	83.5%	.585	.494	.870
	Grade 5	605	73.1%	72.4%	.839	116	69.8%	75.0%	.441	.475	.564
10c	Total	913	31.2%	42.7%	**.000**	237	38.8%	35.0%	.417	**.026**	**.032**
	Grade 3	100	54.0%	61.0%	.392	0	**N too small to report**				
	Grade 4	177	31.1%	57.1%	**.000**	121	47.9%	33.9%	**.033**	**.003**	**.000**
	Grade 5	605	28.1%	36.2%	**.001**	116	29.3%	36.2%	.268	.791	.999
10d	Total	913	29.5%	41.6%	**.000**	237	40.1%	31.6%	**.027**	**.002**	**.005**
	Grade 3	100	33.0%	52.0%	**.005**	0	**N too small to report**				
	Grade 4	177	23.7%	50.8%	**.000**	121	46.3%	28.1%	**.002**	**.000**	**.000**
	Grade 5	605	31.4%	38.0%	**.011**	116	33.6%	35.3%	.851	.639	.586
14*	Total	883	4.27	5.44	**.000**	368	4.09	4.70	**.000**	**.047**	**.000**
	Grade 2	33	**N too small to report**			138	3.27	4.10	**.000**		
	Grade 3	97	3.58	5.57	**.000**	0	**N too small to report**				
	Grade 4	174	3.98	5.31	**.000**	119	4.49	4.84	**.026**	**.001**	**.001**
	Grade 5	579	4.56	5.48	**.000**	111	4.68	5.34	**.000**	.380	.309

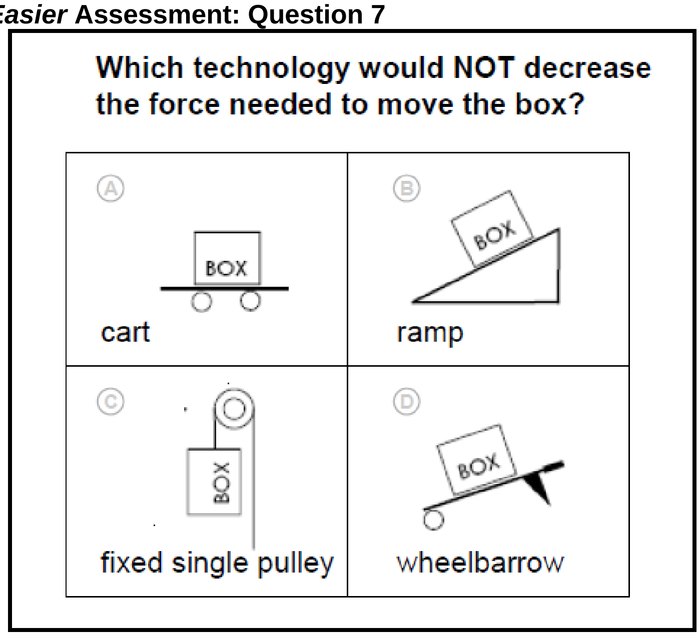
***Question 14 is a composite scale of questions 14a, 14b, 14c, 14d, 14e, and 14f; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-6) for each student.**

Figure 10. ***Making Work Easier*** **Assessment: Question 5**



For question 6, students identified which item was a technology. Students engaging in EiE units learn about technologies. EiE students improved significantly on this question both overall ($p<.001$) and for each grade subset ($p<.001$). Overall, control students also improved significantly ($p<.05$), however the subsets of students by each grade did not improve significantly. EiE students performed significantly better on post-assessments than control students ($p<0.001$) overall and for grade 5 students ($p<.05$).

Figure 11. ***Making Work Easier*** **Assessment: Question 7**



In question 7 (see Figure 11), students chose the technology that would not decrease the force needed to move a box, which pertains to activities done in lesson 3 of the *Making Work Easier* unit. Test students performed significantly better on their post assessments, overall and for students in grades 3 and 4 ($p<.001$). There was no significant change in scores for control students as a whole. However, the grade 4 control students did significantly worse on their post-assessment than their pre-assessments. Also, grade 4 test students performed significantly better on the post-assessments than the grade 4 control students.

Figure 12. ***Making Work Easier*** **Assessment: Question 9**

Alex tested this lever to lift his books. The force required to lift the books was 7 Newtons. He then improved his lever to make it easier to lift his books. The force required to lift the books the same height will now be:

Ⓐ more than 7 Newtons

Ⓑ equal to 7 Newtons

Ⓒ less than 7 Newtons

For question 9 (see Figure 12), students are required to determine what would happen to a force after an improvement on a lever is made. EiE (test) students in all grades did significantly better on their post-assessments than pre-assessments ($p<.001$). There was no significant change in the performance on this question for the control students. On the pre-assessment control students overall and in grade 4 actually scored significantly higher than test students, and on the post-assessment EiE students overall and in grade 5 did significantly better than control students ($p<.001$).

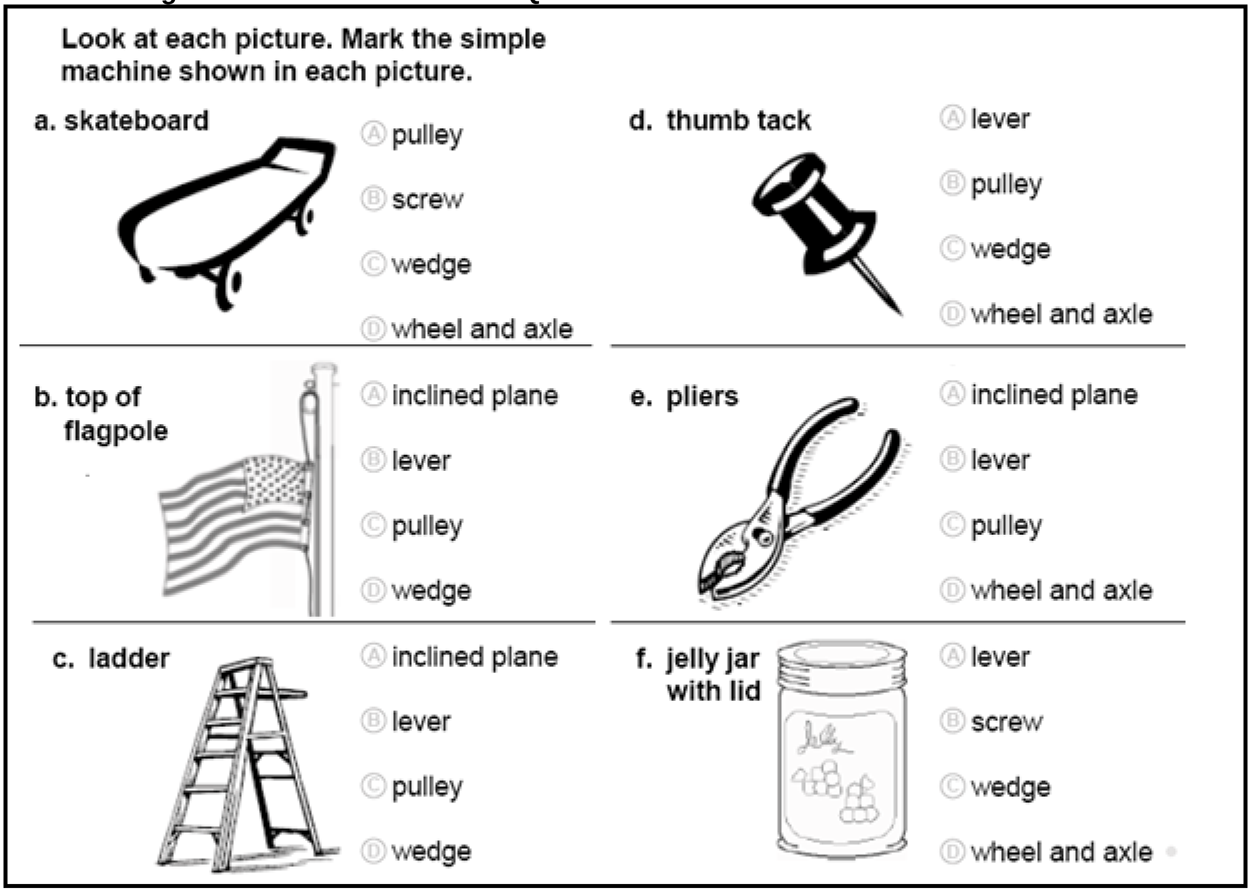
Question 10a asks students to determine if "assembling a backpack" is a process. On the pre-assessment, control students did significantly better than test students in grade 4 ($p<.05$). EiE students did significantly better on post assessments overall ($p<.001$) and for grade 3 ($p=.001$) and grade 4 ($p<.001$). For question 10b, students determined if "a backpack" was an example of a process; there were no significant within group or between group differences.

Question 10c asks students if a double pulley is a process. EiE (test) students overall and in grades 4 and 5 did significantly better on their post-assessments after their science and EiE instruction. Control students in grade 4 did significantly worse on their post-assessment ($p<.05$). On the pre-assessment control students did significantly better than EiE students overall and in grade 4 ($p<.05$). On the post assessment, test students were significantly more likely to answer correctly than control students overall ($p<.05$) and in grade 4 ($p<.001$).

In question 10d, baking cookies was the final process students were given. Test students in each grade did significantly better on their post-assessments after their science and EiE instruction ($p<.001$ overall and grade 4, $p<.05$ grade 3 and grade 5). On the other hand, control students overall and in grade 4 did significantly worse on their post-assessment ($p<.05$). For the pre-assessment control students were more likely than EiE students to answer correctly overall ($p<.05$) and in grade 4 ($p<0.001$) On the post-assessment, test students did significantly better than control students overall ($p<.05$) and in grade 4 ($p<.001$).

The question 14 scale item (see Figure 13) tested students' knowledge of different types of simple machines. This content is assumed to have been covered by the simple machines science instruction given to both control and test students. Both control and test students improved significantly on this question ($p<.001$); students in all test grade levels significantly ($p<.001$) and students in all control grades also improved significantly (grade 2 and grade 5 $p<.001$, and grade 4 $p<.05$). EiE students performed significantly better on the post-assessments than their grade counterparts in the control sample ($p<.001$).

Figure 13. ***Making Work Easier*** **Assessment: Question 14**



"Making Work Easier" Assessment: Gender Differences

Table 12 shows the gender differences for the *Making Work Easier* assessment. Females scored significantly higher on all of their post-assessment than their pre-assessment questions except for questions 7 and 10b ($p<.001$ except questions 3 and 10a $p<.01$). Males scored significantly higher on post-assessments on all questions except for 5 and 10b ($p<.001$ except question 10a and 10d $p<.05$).

On the pre-assessment, males were more likely to answer correctly than females on questions 5, 10c, and 14 ($p<.05$). There were no significant differences between male and female participants for the remaining questions. On the post-assessment, females were more likely to answer correctly than males on question 6 ($p<.05$). Males were more likely to answer correctly than females on questions 3, 7, and 10c ($p<.05$).

Table 26. *Making Work Easier* Assessment: Tests for Gender Differences

	Within-Group Differences (Pre vs. Post)								Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
3	425	53.4%	63.5%	**.003**	440	57.7%	70.3%	**.000**	.202	**.033**
5	432	84.5%	92.4%	**.000**	443	89.6%	91.0%	.545	**.024**	.469
6	451	37.0%	66.2%	**.000**	457	33.5%	58.4%	**.000**	.263	**.016**
7	450	22.2%	27.6%	.058	459	21.8%	34.2%	**.000**	.874	**.030**
9	431	33.2%	58.7%	**.000**	443	38.8%	61.4%	**.000**	.082	.401
10a	435	73.6%	80.9%	**.009**	447	70.2%	77.0%	**.019**	.273	.149
10b	435	76.1%	77.5%	.515	447	72.5%	72.9%	.877	.220	.119
10c	435	28.3%	38.4%	**.000**	447	34.9%	47.9%	**.000**	**.034**	**.004**
10d	435	27.8%	42.5%	**.000**	447	32.2%	41.8%	**.002**	.154	.835
14*	434	4.15	5.39	**.000**	449	4.39	5.48	**.000**	**.008**	.084

***Question 14 is a composite scale of questions 14a, 14b, 14c, 14d, 14e, and 14f; therefore means are reported for this question instead of % correct. The means are calculated from the sum of correct responses (0-6) for each student.**

Summary of the "Making Work Easier" Assessment Results

EiE (test) students performed significantly better on the post-assessment than control students for several questions, and showed significantly more improvement from the pre- to the post-assessment. EiE students significantly improved on all questions except question 10b. EiE students did significantly better than control on the post-assessment in identifying technologies (question 6), determining changes to a force after a lever is improved (question 9), and correctly labeling some technologies as process or not processes (questions10c and 10d). Both EiE and control students improved in identifying simple machines (question 14) on their post-assessments, but for this scale item, EiE students performed significantly better than control students.

On the pre-assessment boys did better than girls on several questions. On the post-assessment, girls did better than boys on a technology question requiring students to select which item was technology. Boys did better on several questions such as one in which they selected the technology that would not decrease the force needed to move the box and in recognizing that a double pulley is not a process. Overall, the *Making Work Easier* unit successfully improved students' knowledge of technology, engineering, and science for both girls and boys.

Results for the Designing Hand Pollinators Unit Questions

In the *Designing Hand Pollinators* EiE curriculum unit, students learn about agricultural engineering and how insects and plants play a role in the natural system of pollination. Science concepts about insects, insect life cycles, pollination, and natural systems are reinforced as students explore the design of hand pollinators. Students identify ways that insects can be problems for an apple orchard and the ways insects can be used as part of an integrated pest management solution (Lesson 2). They then conduct a controlled experiment to determine what materials would work best to create a hand pollinator (Lesson 3). Finally, students use what they have learned to design and test their own hand pollinators (Lesson 4).

The *Designing Hand Pollinators* assessment was designed and first tested during Year 3 of the EiE project (the 2005-2006 school year). It was revised during 2006-2007, when a number of questions were dropped or changed. The assessment was again administered to PCET control students during the 2006-2007 school year and PCET field test students during the 2007-2008 school year.

The test sample included 340 students who completed both a science unit on insects or plants and the EiE unit *Designing Hand Pollinators* between the pre-assessment and post-assessment administrations. There were 497 control students who completed only a science unit on insects or plants after the pre-assessment and before the post-assessment was administered. Table 27 describes the distribution of students in both samples by grade. Both control and test teachers were free to use whatever science curriculum they wished to complete the required insects or plants science instruction during the field test period.

Table 27. *Designing Hand Pollinators* Assessment: Sample Size by Grade

		Grade				Total
		2	3	4	5	
Control	Count	73	109	98	217	497
	% of Sample	14.7%	21.9%	19.7%	43.7%	100.0%
Test	Count	134	61	145	-	340
	% of Sample	39.4%	17.9%	42.6%	-	100.0%
Total	Count	207	170	243	217	837
	% of Sample	24.7%	20.3%	29.0%	25.9%	100.0%

Girls made up 48.9% of the control sample, and 53.4% of the test sample, a difference which was not significant (Pearson Chi-Square p=.201). Race/Ethnicity information was gathered for test and control students, but too few students made up each ethnicity group to report on this separately.

Table 28 describes the racial/ethnic distribution of the student population. White students made up the majority of both the control and test samples. Asian students made up the second largest population within each sample – 7.1% of the control sample, and 6.8% of the test sample. The test sample was 5.9% Black and 3.1% Hispanic, while the control sample was 4.9 % Black and 2.0% Hispanic. Differences by race/ethnicity are not reported because there are too few students in each category for analysis.

Table 28. *Designing Hand Pollinators* Assessment: Sample Size by Race/Ethnicity

		Black	Asian	Hispanic	White	Other	Total
Control	Count	24	35	10	420	3	492
	% of sample	4.9%	7.1%	2.0%	85.4%	0.6%	100.0%
Test	Count	19	22	10	268	5	324
	% of sample	5.9%	6.8%	3.1%	82.7%	1.5%	100.0%
Total	Count	43	57	20	688	8	816
	% of sample	5.3%	7.0%	2.4%	84.3%	1.0%	100%

"Designing Hand Pollinators" Assessment Questions and Analysis

On the pre- and post-assessments these students were asked questions about insects, plants, pollination, pest prevention, and the field of agricultural engineering. The questions were given to both groups of EiE (test) and control students in grades 2 through 5. Table 29 describes the text for the questions with the correct answer(s) shown in brackets. Students in grades 3 through 5 received all questions, while grade 2 students only received questions 7a-d, 12a-g, 13, and 14.

Table 29. *Designing Hand Pollinators* Assessment: Questions (Text)

Question #	Answered by	Text of component questions [answer]
4	Grades 3-5	Paper wasps eat caterpillars. Caterpillars eat tomato plants. If Mario kills the paper wasps in his garden, what will probably happen? [A: there will be more caterpillars eating his tomato plants] (Figure 14)
6	Grades 3-5	Ari sees insects flying around his favorite pumpkin plants. He is worried they might be hurting his plants. What do you think should do FIRST to make sure the insects aren't hurting his plants? [B: Observe the insects to learn what they are doing]
7 (a-d)	Grades 2-5	Melissa is designing a hand pollinator. Look at the list below. Mark ALL of the things that she should consider when she designs her hand pollinator. a. the shape of the flower [True] b. the color of the flower [False] c. if the pollinator can pick up pollen [True] d. if the pollinator can drop off pollen [False]
8	Grades 3-5	Lenore notices that the insects that used to pollinate her favorite flower don't live in her garden anymore. What is the BEST way for her to pollinate her flowers? [D: Pollinate the flower by hand]
10	Grades 3-5	Pollinating insects are useful to plants because they: [D: move pollen from one flower to another]
11	Grades 3-5	Which part of this plant is NOT part of the pollination system? [C: leaves] (Figure 15)
12 (a-g)	Grades 2-5	Look at the list below. Mark ALL of the things that agricultural engineers might do for their work. a. figure out how to keep insects from eating crops [True] b. improve a way to pollinate plants that people use for food [True] c. figure out the best way to water fields [True] d. drive a tractor to harvest food [False] e. fix tractors when they break down [False] f. plant food crops for people to eat [False] g. design a tractor engine [False]
13	Grades 2-5	Why do insects like bees and butterflies visit flowers? [B: to get nectar]
14	Grades 2-5	True or False? Most flowering plants need insects to help them make seeds. [A: true]

Significant changes from the pre-assessment to the post-assessment (within-group differences) were analyzed for individually reported items using McNemar's Test of Symmetry. Between-group differences (test vs. control) were analyzed using the phi coefficient.

Table 30 and Table 31 report the analysis of the Designing Hand Pollinators unit assessment. Percent correct on the pre- and post- is reported for each question listed in the left-most column. For the within-groups analysis, McNemar's chi-square was used to test significance for the binary values (correct or incorrect). The chi-square phi statistic was used to test for significant differences between the control and test groups for all questions. The numbers of control students in grade 5 are included in the overall results for the control sample. However, no individual results for grade 5 students in the control sample are included because there were no grade 5 students in the EiE (test) sample.

Items 7a, 7b, 7c, and 7d are all choices for a single question asking students to identify things that should be considered when making a hand pollinator. The questions were administered to students in grades 2 through 5. An attempt was made to combine items 7a, 7b, 7c, and 7d into a single scale; however Reliability Analysis in SPSS found Cronbach's α to be lower than .7, so they were analyzed as individual items. The same was true for the seven items of question 12. These items will be revised in 2009 when the *Designing Hand Pollinators* assessment is revisited for further use.

Table 30. *Designing Hand Pollinators* Assessment: Results, Questions 4-11

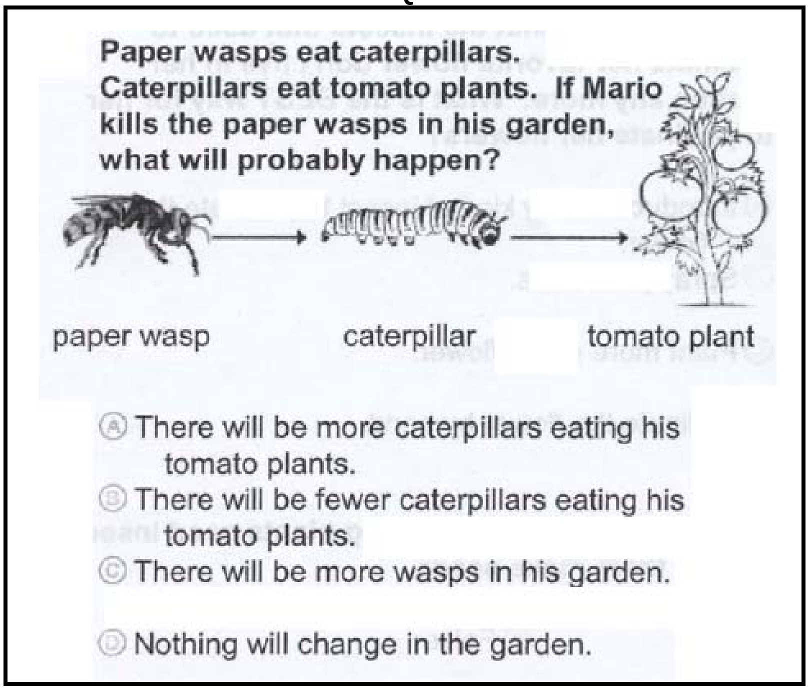
		Within-Group Differences (Pre vs. Post)								**Test / Control Differences**	
		EiE Test				**EiE Control**				**PRE**	**POST**
Q#	**Group**	**N**	**Pre**	**Post**	**p=**	**N**	**Pre**	**Post**	**p=**	**p=**	**p=**
4	Total	202	83.7%	84.2%	1.000	422	76.3%	89.8%	**.000**	**.036**	**.042**
	Grade 3	61	90.2%	91.8%	1.000	108	57.4%	86.1%	**.000**	**.000**	.271
	Grade 4	141	80.9%	80.9%	1.000	98	78.6%	89.8%	**.043**	**.000**	.060
	Grade 5	0	**N too small to report**			216					
6	Total	205	71.2%	84.4%	**.000**	420	71.4%	85.5%	**.000**	.957	.720
	Grade 3	61	60.7%	88.5%	**.000**	107	57.0%	77.6%	**.000**	.645	.078
	Grade 4	144	75.7%	82.6%	.121	97	71.1%	88.7%	**.000**	.429	.198
	Grade 5	0	**N too small to report**			216					
7a	Total	340	51.2%	60.3%	**.009**	497	44.5%	44.9%	.942	.066	**.000**
	Grade 2	134	51.5%	55.2%	.560	73	39.7%	50.7%	.169	.105	.532
	Grade 3	61	50.8%	68.9%	.071	109	49.5%	38.5%	.073	.873	**.000**
	Grade 4	145	51.0%	61.4%	.053	98	33.7%	39.8%	.418	**.007**	**.001**
	Grade 5	0	**N too small to report**			217					
7b	Total	340	65.6%	88.2%	**.000**	497	75.7%	82.9%	**.001**	**.002**	**.033**
	Grade 2	134	49.3%	81.3%	**.000**	73	56.2%	64.4%	.327	.342	**.007**
	Grade 3	61	65.6%	91.8%	**.002**	109	72.5%	71.6%	1.000	.346	**.002**
	Grade 4	145	80.7%	93.1%	**.001**	98	79.6%	91.8%	**.004**	.833	.711
	Grade 5	0	**N too small to report**			217					
7c	Total	340	81.2%	92.6%	**.000**	497	80.1%	86.5%	**.003**	.694	**.005**
	Grade 2	134	70.1%	94.8%	**.000**	73	67.1%	78.1%	.134	.653	**.000**
	Grade 3	61	86.9%	96.7%	.109	109	69.7%	84.4%	**.009**	**.012**	**.014**
	Grade 4	145	89.0%	89.0%	1.000	98	86.7%	90.8%	.454	.599	.641
	Grade 5	0	**N too small to report**			217					
7d	Total	340	63.8%	84.1%	**.000**	497	70.6%	79.9%	**.000**	**.039**	.120
	Grade 2	134	42.5%	79.1%	**.000**	73	50.7%	61.6%	.185	.261	**.007**
	Grade 3	61	82.0%	96.7%	**.022**	109	56.9%	79.8%	**.000**	**.001**	**.002**
	Grade 4	145	75.9%	83.4%	.099	98	72.4%	82.7%	**.041**	.549	.871
	Grade 5	0	**N too small to report**			217					
8	Total	204	29.4%	66.7%	**.000**	413	22.8%	25.4%	.363	.072	**.000**
	Grade 3	61	21.3%	83.6%	**.000**	104	25.0%	24.0%	1.000	.590	**.000**
	Grade 4	143	32.9%	59.4%	**.000**	97	22.7%	25.8%	.711	.087	**.000**
	Grade 5	0	**N too small to report**			212					
10	Total	201	69.2%	84.1%	**.000**	415	58.6%	74.9%	**.000**	**.011**	**.010**
	Grade 3	61	75.4%	96.7%	**.001**	104	43.3%	76.0%	**.000**	**.000**	**.001**
	Grade 4	140	66.4%	78.6%	**.012**	97	60.8%	70.1%	.150	.376	.138
	Grade 5	0	**N too small to report**			214					
11	Total	199	83.4%	92.0%	**.008**	413	74.8%	85.2%	**.000**	**.017**	**.019**
	Grade 3	58	82.8%	91.4%	.267	104	63.5%	73.1%	.184	**.010**	**.006**
	Grade 4	141	83.7%	92.2%	**.023**	94	81.9%	94.7%	**.008**	.723	.459
	Grade 5	0	**N too small to report**			215					

Table 31. ***Designing Hand Pollinators*** **Assessment: Results, Questions 12-14**

		Within-Group Differences (Pre vs. Post)								Test / Control Differences	
		EiE Test				EiE Control				PRE	POST
Q#	Group	N	Pre	Post	p=	N	Pre	Post	P=	p=	p=
12a	Total	340	52.6%	78.5%	**.000**	497	54.3%	59.4%	.066	.632	**.000**
	Grade 2	134	47.0%	73.9%	**.000**	73	43.8%	53.4%	.281	.661	**.003**
	Grade 3	61	72.1%	86.9%	.093	109	56.9%	56.9%	1.000	**.049**	**.000**
	Grade 4	145	49.7%	79.3%	**.000**	98	54.1%	52.0%	.864	.498	**.000**
	Grade 5	0	**N too small to report**			217					
12b	Total	340	44.4%	72.6%	**.000**	497	47.3%	55.3%	**.005**	.413	**.000**
	Grade 2	134	45.5%	69.4%	**.000**	73	41.1%	46.6%	.572	.540	**.001**
	Grade 3	61	45.9%	85.2%	**.000**	109	42.2%	54.1%	.092	.641	**.000**
	Grade 4	145	42.8%	70.3%	**.000**	98	42.9%	53.1%	.143	.988	**.006**
	Grade 5	0	**N too small to report**			217					
12c	Total	340	47.4%	51.2%	.326	497	49.7%	53.1%	.247	.505	.581
	Grade 2	134	38.1%	41.0%	.694	73	41.1%	47.9%	.458	.669	.339
	Grade 3	61	63.9%	59.0%	.690	109	40.4%	37.6%	.766	**.003**	**.007**
	Grade 4	145	49.0%	57.2%	.175	98	40.8%	53.1%	.081	.211	.520
	Grade 5	0	**N too small to report**			217					
12d	Total	340	65.3%	83.8%	**.000**	497	67.4%	68.8%	.664	.525	**.000**
	Grade 2	134	66.4%	76.1%	.111	73	58.9%	39.7%	**.038**	.283	**.000**
	Grade 3	61	62.3%	88.5%	**.000**	109	71.6%	71.6%	1.000	.213	**.011**
	Grade 4	145	65.5%	89.0%	**.000**	98	69.4%	77.6%	.215	.529	**.016**
	Grade 5	0	**N too small to report**			217					
12e	Total	317	51.2%	82.6%	**.000**	497	57.3%	56.3%	.771	.139	**.000**
	Grade 2	134	50.7%	78.4%	**.000**	73	42.5%	39.7%	.851	.254	**.000**
	Grade 3	61	59.0%	90.2%	**.000**	109	63.3%	52.3%	.126	.581	**.000**
	Grade 4	122	50.0%	83.6%	**.000**	98	63.3%	65.3%	.864	**.049**	**.002**
	Grade 5	0	**N too small to report**			217					
12f	Total	317	62.5%	71.6%	**.012**	497	61.8%	62.2%	.941	.843	**.006**
	Grade 2	134	67.9%	72.4%	.480	73	58.9%	50.7%	.307	.195	**.002**
	Grade 3	61	59.0%	52.5%	.481	109	60.6%	60.6%	1.000	.845	.306
	Grade 4	122	58.2%	80.3%	**.000**	98	68.4%	69.4%	1.000	.121	.061
	Grade 5	0	**N too small to report**			217					
12g	Total	317	49.2%	65.6%	**.000**	497	56.3%	52.3%	.157	**.047**	**.000**
	Grade 2	134	44.0%	62.7%	**.002**	73	52.1%	43.8%	.327	.269	**.009**
	Grade 3	61	60.7%	85.2%	**.003**	109	65.1%	53.2%	.092	.560	**.000**
	Grade 4	122	49.2%	59.0%	.111	98	58.2%	53.1%	.487	.184	.376
	Grade 5	0	**N too small to report**			217					
13	Total	329	62.6%	68.7%	.082	489	66.9%	72.6%	**.034**	.210	.227
	Grade 2	126	54.8%	60.3%	.401	70	51.4%	72.9%	**.006**	.654	.078
	Grade 3	61	73.8%	82.0%	.383	106	66.0%	66.0%	1.000	.299	**.028**
	Grade 4	142	64.8%	70.4%	.312	97	67.0%	76.3%	.175	.722	.317
	Grade 5	0	**N too small to report**			216					
14	Total	315	67.0%	80.6%	**.000**	487	52.4%	57.7%	.072	**.000**	**.000**
	Grade 2	133	69.9%	80.5%	**.038**	72	40.3%	36.1%	.648	**.000**	**.000**
	Grade 3	61	65.6%	93.4%	**.001**	105	41.0%	70.5%	**.000**	**.002**	**.000**
	Grade 4	121	64.5%	74.4%	.126	97	56.7%	47.4%	.211	.243	**.000**
	Grade 5	0	**N too small to report**			213					

Question 4 (see Figure 14) was administered to students in grades 3 through 5. EiE (test) students did improve overall, but not significantly. Control students did improve significantly, both overall ($p<.001$) and in grade 3 ($p<.001$), grade 4 ($p=.043$), and grade 5 ($p=.011$). However, these differences may be due in part or entirely to the fact that test students did significantly better on the pre-assessment than control (p<.05).

Figure 14. Designing Hand Pollinators Assessment: Question 4



Question 6 tests students' willingness to use a scientific "watch and see" strategy to solve a problem. EiE students improved significantly overall (p<.001) and in grade 3 (p<.001). Control students also improved significantly overall (p<.001) as well as in grade 3 (p<.001) and grade 4 (p<.001). There were no significant between-group differences to report on the pre- or post-assessments.

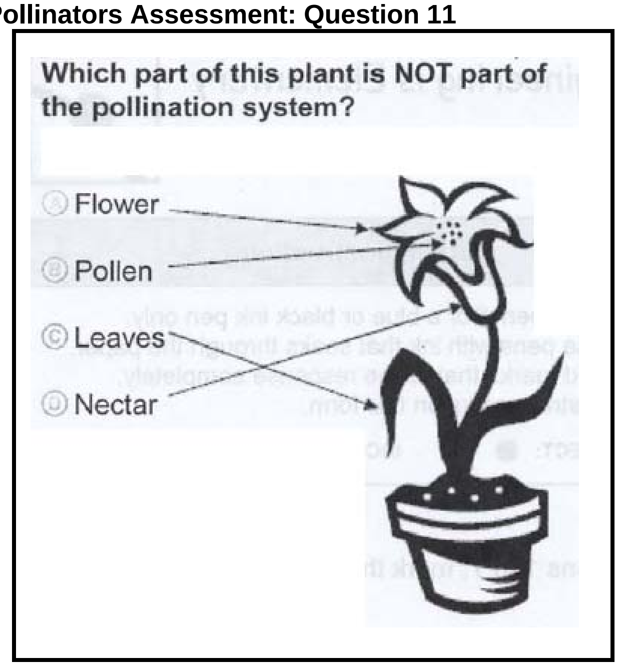
EiE (test) students improved significantly overall on questions 7a (p=.009), 7b (p<.001), 7c (p<.001), and 7d (p<.001). By grade, EiE students' improvements were significant in grades 2 through 4 for 7b, grade 2 for 7c (p<.001), and grades 2 and 3 for 7d. Control students overall improved significantly on 7b (p=.001), 7c (p=.003), and 7d (p<.001). By grade, control students improved significantly on 7a and 7b in grade 4 (p<.01), 7c in grade 3 (p<.01), and 7d in grade 3 (p<.001) and grade 4 (p=.041). Between groups, test students did significantly better than control students on the post-assessment for 7a (p<.001), 7b (p<.05), and 7c (p<.01). For 7a, the between-group differences on the post-assessment were significant for grade 3 (p<001) and grade 4 (p=.001). For 7b, 7c, and 7d, EiE did significantly better on the post-assessment in grade 2 and grade 3. From the found results, EiE students showed significant improvements across more grade levels than control students for questions 7a, 7b, 7c, and 7d. EiE students also performed significantly better on the post-assessment overall.

Test students overall improved significantly on question 8 (p<.001); they improved specifically in grade 3 (p<.001) and grade 4 (p<.001). Control students did not improve significantly overall or individually in any grade level. Between groups, EiE students performed significantly better than control students on the post-assessment overall (p<.001), and in grade 3 (p<.001) and grade 4 (p<.001). There were significant between-group differences on the pre-assessment, therefore EiE students ultimately improved more and performed better than control students on this question.

Question 10 asks students to identify why pollinating insects are useful to plants. EiE students improved significantly overall (p<.001) and in grade 3 (p=.001) and grade 4 (p=.012). Control students improved significantly overall (p<.001) and in grade 3 (p<.001). Between-groups, EiE students performed better than control students overall on the pre-assessment (p=.011) and on the post-assessment (p=.010), and in grade 3 on the pre- (p<.001) and post-assessment (p=.001).

Question 11 (see Figure 15), given to students in grades 3 through 5, depicts a picture of a potted flower. Students are asked to indicate which of four parts of the plant (arrows link each part name with its location on the picture) is not part of the pollination system. The choices are flower, pollen, leaves, nectar [answer: leaves]. EiE (test) students improved significantly overall (p=.008) and in grade 4 (p=.023). Control students improved significantly overall (p<.001) and in grade 4 (p=.008) as well. Between-groups, EiE students performed better than control students overall on the post-assessment (p=.019), and also in grade 3 (p=.006).

Figure 15. Designing Hand Pollinators Assessment: Question 11



Items 12a-g are all choices for a single question asking students what agricultural engineers might do for their work. Students (grades 2 through 5) are directed to mark all answers that fit. EiE (test) students overall improved significantly on items 12a-e (p<.001), 12f (p<.05), and 12g (p<.001). Their improvements were significant for grades 2, 3, and 4 for most items. Control students improved significantly overall on 12b (p<.01) only, and on 12d for grade 2 (p<.05). Between-groups, EiE students performed significantly better than control students overall on 12a, b, d, e, and g (p<.001), and also on 12f (p<.01). Between-group differences overall on the pre-assessment were only significant for 12g, and barely so (p=.047). Therefore, EiE students ultimately performed better and improved more than control students on question 12 overall.

Question 13, given to students in grades 2 through 5, asks why insects visit flowers. The choices are 'to get pollen', 'to get nectar', 'to eat the petals', and 'to find a place to live' [answer: to get nectar]. EiE (test) students did not show significant improvements on this question, but control students did overall (p<.05) and in grade 2 (p<.01). Between-groups, EiE students in grade 3 performed significantly better than control students on the post-assessment (p<.05).

Question 14, also given to students in grades 2 through 5, asks students to indicate whether the statement 'Most flowering plants need insects to help them make seeds.' Is true or false [answer: true]. EiE (test) students improved significantly overall (p<.001), in grade 2 (p<.05), and in grade 3 (p=.001). Control students improved significantly in grade 3 only (p<.001). EiE students performed significantly better than control students on the post-assessment overall and in grades 2, 3, and 4 (p<.001).

"Designing Hand Pollinators" Assessment: Gender Differences

Table 32 shows the gender differences for the *Designing Hand Pollinators* assessment. Both females and males improved significantly on most questions. Between genders the only significant differences are seen on the pre-assessment for questions 7a and 12f, for which males performed significantly better than females (p<.05 for 7a, p<.05 for 12f). There were no significant between-gender differences on the post-assessment for any question items.

Table 32. *Designing Hand Pollinators* Assessment: Tests for Gender Differences (Test Students Only)

Within-Group Differences (Pre vs. Post)									Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	p=	N	Pre	Post	p=	p=	p=
4	106	81.1%	83.0%	.824	96	86.5%	85.4%	1.000	.307	.641
6	107	73.8%	86.9%	**.009**	98	68.4%	81.6%	**.024**	.388	.298
7a	181	56.4%	62.4%	.235	158	45.6%	57.6%	**.018**	**.048**	.364
7b	181	66.3%	86.7%	**.000**	158	64.6%	89.9%	**.000**	.737	.372
7c	181	80.7%	93.9%	**.000**	158	81.6%	91.1%	**.014**	.818	.328
7d	181	61.3%	82.9%	**.000**	158	66.5%	85.4%	**.000**	.327	.519
8	106	30.2%	65.1%	**.000**	98	28.6%	68.4%	**.000**	.800	.620
10	104	65.4%	83.7%	**.000**	97	73.2%	84.5%	.061	.231	.864
11	104	87.5%	90.4%	.629	95	78.9%	93.7%	**.003**	.105	.393
12a	181	50.3%	77.9%	**.000**	158	55.1%	79.1%	**.000**	.379	.786
12b	181	42.5%	73.5%	**.000**	158	46.2%	72.2%	**.000**	.498	.784
12c	181	45.9%	49.2%	.594	158	48.7%	53.8%	.366	.596	.395
12d	181	65.7%	82.9%	**.000**	158	65.2%	84.8%	**.000**	.914	.629
12e	169	52.7%	83.4%	**.000**	147	51.0%	81.6%	**.000**	.771	.674
12f	169	68.0%	70.4%	.704	147	55.8%	72.8%	**.002**	**.025**	.641
12g	169	47.9%	61.5%	**.009**	147	50.3%	70.1%	**.000**	.669	.112
13	176	63.6%	71.0%	.136	152	61.2%	66.4%	.341	.647	.372
14	168	66.7%	80.4%	**.009**	146	67.1%	80.8%	**.005**	.932	.917

Summary of the "Designing Hand Pollinators" Assessment Results

EiE (test) students performed significantly better on the post-assessment than control students on most questions. EiE students also showed larger improvements from the pre- to post-assessment on most questions. These improvements are especially visible on the items of question 12, where pre- to post-assessment improvements were significant for EiE students but not for control students.

EiE students did significantly better than control students on the pre-assessment on four of the five science questions (4, 10, 11, and 14). It is possible that some field test teachers gave the pre-assessments after science instruction began. There was some confusion about when to give the pre-assessment to EiE students because this unit connects with two science topics (insects and plants).

The performance of boys and girls was not significantly different overall. Boys outperformed girls on the pre-assessment for only two questions, and the two genders did not perform significantly different on the post-assessment for any question. Both girls and boys showed significant pre- to post-assessment improvements on most questions.

Conclusion

Though the results are not always clear, the trends of this analysis show that the students of PCET teachers learned more about engineering, technology, and often science after their teachers attended the PCET summer institute and implemented the EiE curriculum. This analysis looked at students who learned about engineering in conjunction with science, in comparison to those who learned only about science (from the same teachers).

EiE students:

- Agree more strongly than control students that scientists and engineers make peoples' lives better after completing an EiE unit.
- Are more likely to report that they would enjoy being an engineer or a scientist
- Are often significantly more likely to correctly answer science content questions relating to the unit after completing an EiE unit.
- Are much more likely to correctly identify the work of the field of engineers related to the unit on the post-assessment after completing the EiE units *Designing Bridges*, *Designing Windmills*, and *Designing Hand Pollinators*.
- Are much more likely to correctly identify relevant aspects and types of technologies featured in the unit after completing the EiE units *Designing Bridges*, *Designing Windmills*, *Making Work Easier*, and *Designing Hand Pollinators*.
- Demonstrate a much clearer understanding of relevant criteria for a design after completing the *Designing Windmills* and *Designing Hand Pollinators* units.
- Demonstrate a clearer understanding of materials, their properties, and their uses in different engineering design scenarios after completing the EiE unit *Designing Walls*.
- Demonstrate a clearer understanding of the engineering design process after completing the *Designing Walls* unit.

Our philosophy is that children construct a much deeper understanding of the world around them—including science, technology, and engineering—when they interact with meaningful, challenging activities. The findings reported here provide evidence for the pedagogy and teacher professional development methods we espouse as well as the quality of the *Engineering is Elementary* curriculum.

An important goal of engineering education in the elementary grades is to introduce students to engineering as a profession which takes skill, creativity, and knowledge of science and mathematics, but which novices can begin to practice in an intellectually honest way, just as they can practice scientific inquiry at an amateur level in an intellectually honest way. We want students to feel that engineering design can be fun, can help people, and is worth learning to do better. In addition, we want them to be exposed to the enormous range of technologies in use today, as well the enormous inheritance they receive of accumulated design know-how. Engineering is ongoing, and can be used to solve human problems. These are goals worthy of students' time and effort.

Bibliography

[1] C. M. Cunningham and K. Hester, "Engineering is Elementary: An Engineering and Technology Curriculum for Children," presented at American Society for Engineering Education Annual Conference & Exposition, Honolulu, HI, 2007.

[2] S. J. Gibbons, L. S. Hirsch, H. Kimmel, R. Rockland, and J. Bloom, "Middle school students' attitudes to and knowledge about engineering," presented at International Conference on Engineering Education, Gainesville, FL, 2004.