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

Engineering is Elementary
The National Center for Technological Literacy
Museum of Science, Boston

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Engineering is Elementary
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Abstract

Findings are presented from a research program conducted by the *Engineering is Elementary* curriculum development project. Students participating in testing of the EiE curriculum materials were given pre-assessments and post-assessments that included questions about general engineering and technology concepts, engineering questions specific to particular units, and questions on science topics relevant to particular units. For some topics, a comparable control sample of students who did not study EiE curriculum units was also assessed. Analysis of the data shows that students participating in EiE performed significantly better on the post-assessments than on the pre-assessments. They also performed significantly better than control students on the post-assessments. The engineering, technology, and science understandings of students participating in EiE significantly increased due to participation in EiE curriculum units.

Engineering is Elementary

Engineering is Elementary (EiE) is a curriculum designed to teach elementary students about concepts in engineering and technology. The curriculum is made up of individual units each of which is intended to supplement and enhance the teaching of a specific science topic. Ten (of twenty planned) units have been distributed and tested in classrooms so far. Each unit is organized around the design of a specific technology, and is associated with a field of engineering: for example, one unit is named *Water, Water Everywhere: Environmental Engineering and Designing Water Filters.* Each unit begins with a story about a child who solves a problem using the engineering design process, learned from a relative or other mentor (Lesson 1). The stories are often set internationally, and feature a real or realistic technology in development, in order to provide a context for the lessons. Each unit also includes additional lessons where students investigate and test materials and processes for their designs, and culminates in a final design challenge (Lesson 4). A complete description of the EiE curriculum and its goals can be found in the ASEE 2007 conference proceedings [1].

The Research Program

As we have developed these curriculum units, the EiE team has collected pre- and post-assessments from students in classrooms field testing the units. Field testing classrooms come from six states in different regions of the United States: California, Colorado, Florida, Minnesota, Massachusetts, and New Jersey. In 2005-2006, we also collected pre- and post-assessments from classrooms in one district in Massachusetts that did not complete any EiE units (control classrooms). The purpose of data collection has been and continues to be twofold: (1) to learn more about what students nationally know about engineering, technology, and the engineering design process and (2) to evaluate the *Engineering is Elementary* curriculum in terms of its effect on students' understanding of engineering, of technology, and of related science topics.

In this paper, we show that EiE students have learned about science and engineering from the six EiE units which were tested nationally during the 2005-2006 school year:

- *Designing Water Filters*
- *Designing Walls*
- *Designing Bridges*
- *Designing Windmills*
- *Making Work Easier*
- *Designing Hand Pollinators*

For each of these units, we collected pre- and post-assessments.

Pre- and post-assessments consist of a variety of multiple-choice, fill-in-the-blank, and choose-all-that-apply questions. Each participating EiE student received one assessment on general engineering and/or technology topics and other assessments specific to each unit they studied. Control students received a variety of questions from different unit assessments and from the general engineering assessment. Each unit assessment includes both science and engineering questions that are relevant to that unit. Where possible, pre-assessments were given in October or November, and post-assessments in May or June of the same school year. However, due to the varying circumstances of individual teachers, sometimes the pre-assessments were given later in the school year or the post-assessments earlier. For example, some assessments were administered by science specialists who saw their students for only a portion of the year. Others were administered by teachers who first learned about the project and signed up to field test an EiE unit in January. In all cases, teachers were instructed to administer pre-assessments before instruction in any EiE unit and related science topics, and post-assessments were administered after instruction was completed.

Because the time period between pre- and post-assessment is larger than just a few weeks, maturation effects can be reasonably expected. One reason to include the control sample is to get a measurement of what change we can expect on the post-assessment after four to six months. As we will explain below, we often see significant improvement on the post-assessment by control students, but this improvement is rarely as large as the improvements made by students who have participated in EiE. Also, EiE students make more consistent significant improvements on assessment questions than control students.

The Samples

Where possible, student responses (called EiE or Test below) were compared to responses from a control sample. EiE responses were drawn from a national sample consisting of students from Massachusetts, New Jersey, Florida, Colorado, Minnesota, and California. Control responses were collected from one district in Massachusetts. Though the samples were different in some demographics—particularly as a larger proportion of the control sample receives free or reduced lunch— preliminary post-hoc examination of the data has not shown evidence of interaction effects.

For many of the unit questions, control data was collected from EiE classrooms who were completing non-related units. For example, students completing the *Designing Walls* unit might have completed an assessment from the *Making Work Easier* unit as control. These “EiE Control” assessments were used as comparison with assessments from students who did complete the *Making Work Easier* unit.

Limits and Weaknesses of the Sample

This report represents the first year of major data collection. Due to problems with getting assessments back from teachers, the number of students who completed each type of assessment varied widely. The distribution across grades also varied widely; because subsequent analysis found that there were frequently significant differences between grades, we expect these differences to impact our results: a sample that was mostly composed of fifth-grade students will perform differently from one composed of mostly second-grade students. Also, a sample of 400 students is more likely to show significant effects than a similarly composed sample of only 50 students.

Another problem that emerged was variation in science instruction. We had expected all teachers would complete related science instruction with the EiE unit; however post-unit feedback indicated that many teachers had not completed any related science instruction, while others completed the related science instruction long before they began the EiE unit or administered its pre-assessment. Because of the lack of information, we are not certain whether and to what extent concurrent science instruction impacts performance on the assessments. Current data collection includes significant efforts to determine when and for how long related science units are being taught, and to coordinate these with EiE data collection.

Most recently we have begun to match separate EiE and Control samples based on grade and science taught. Efforts are currently underway to collect this control data from a wider geographic distribution of students on all new questions.

Sample Size

We are working with a sample size of 5,139 students who used the EiE curriculum and 1,827 students from the control sample who did not use any EiE curriculum. Each EiE student completed a portion of the General Engineering assessment, as well as questions from the EiE unit(s) he or she completed. Each control student completed 1/3 of the General Engineering assessment (questions randomly assigned), and a small number of EiE unit questions (also randomly assigned). The EiE sample is larger than the control sample for all questions.

Table 1. Sample Size by Grade, by State

	CA	CO	FL	MA (Test)	MA (Control)	MN	NJ	Other
Grade 2	0	127	101	547	256	231	0	0
Grade 3	86	134	55	343	498	189	41	0
Grade 4	159	169	89	385	515	256	150	0
Grade 5	276	131	277	707	558	258	195	14
Grade 6	0	0	0	35	0	184	0	0
Total	521	561	522	2,017	1,827	1,118	386	14

Grade

Grades 2 through 6 were represented in the sample. Very few grade 6 students participated—all of them in the test (EiE) sample. Fewer grade 2 students participated than grades 3, 4, or 5. The differences between the control and EiE samples on grade were not statistically significant (Nominal by Interval Eta $p=.052$).

Table 2.							
		Grade					Total
		2	3	4	5	6	
Control	Count	256	498	515	558	0	1827
	% of Sample	14.0%	27.3%	28.2%	30.5%	0.0%	100.0%
EiE	Count	1006	848	1208	1858	219	5139
	% of Sample	19.6%	16.5%	23.5%	36.2%	4.3%	100.0%
Total	Count	1262	1346	1723	2416	219	6966
	% of Sample	18.1%	19.3%	24.7%	34.7%	3.1%	100.0%

Gender

Gender differences between the Control and EiE test populations were insignificant (p=.612), with both populations being split roughly 50-50%.

Free and Reduced Lunch

The Control sample has a significantly higher proportion of students receiving free or reduced lunch (Goodman & Kruskal Tau-b p=.000). 69.1% of the Control sample reporting receives free or reduced lunch, as compared to only 30.4% of the EiE sample reporting.

Limited English Proficiency

Of those reporting (n=1329), 7.3% of the Control students were classified as Limited English Proficient (LEP). 4.8% of EiE students reporting (n=1817) were classified as LEP. This difference was significant (Phi Coefficient p=.004).

Race/Ethnicity

Significant differences in racial makeup between the Control and EiE samples exist (Goodman & Kruskal Tau-b p=.000). The Control sample has proportionally more White students (78.4% versus 65.0%). The EiE sample has larger proportions of Black (9.9% versus 8.8%), Asian (9.9% versus 4.3%) and Hispanic (13.4% versus 7.9%) students among those reporting (n=3002).

Table 3. Sample Size by Grade, per Unit

Race/ Ethnicity	White	Hispanic /Latino	Black	Asian	Native American	Multi-racial	Other	Total
Control (Mass.)	78.4%	7.9%	8.8%	4.3%	0.6%	0.0%	0.1%	100.0%
EiE (Total)	65.2%	13.5%	9.9%	9.2%	0.7%	1.6%	0.2%	100.0%
EiE California	52.8%	16.6%	8.6%	21.0%	0.3%	0.3%	0.3%	100.0%
EiE Colorado	72.6%	11.1%	10.8%	4.5%	0.8%	0.3%	0.0%	100.0%
EiE Florida	18.1%	44.0%	31.5%	2.8%	0.0%	3.7%	0.0%	100.0%
EiE Mass.	73.0%	9.5%	6.8%	8.2%	0.4%	2.0%	0.1%	100.0%
EiE Minnesota	71.3%	1.6%	9.8%	13.1%	0.8%	3.3%	0.0%	100.0%
EiE New Jersey	57.6%	16.8%	10.7%	11.3%	2.4%	0.3%	1.0%	100.0%
Total	70.1%	11.3%	9.5%	7.3%	0.6%	1.0%	0.2%	100.0%

Dramatic differences also exist between states. Florida has proportionally the smallest White population (18.1%) and the largest Hispanic population (44.0%). California and New Jersey also have relatively low White populations (52.8% and 57.6% respectively) and high Hispanic populations (16%). California also has the largest proportion of Asian students (21.0%).

Pre-Post Differences on General Engineering Questions

EiE students were tested twice—once before the Engineering is Elementary unit was begun, and once after it was completed—allowing for a test-retest analysis. Student responses were scored as "correct" or "incorrect" before beginning analysis. Since all results were therefore binomial, significant changes from the pre-assessment to the post-assessment were analyzed using McNemar's Test of Symmetry, a crosstabulation analysis designed for binomial nominal data. Differences between the test subjects (EiE students) and the control subjects were analyzed using the phi coefficient. This chi-square variant is designed for analyzing dichotomous data; its value approaches that of Pearson's chi-square for high values of N, an expectation which was confirmed in this analysis.

Each classroom of students did a different subset of the General Engineering questions, so it was not possible to obtain an overall "general engineering & technology" score for each student.

What is Technology?

For the "What is Technology?" question, students were asked to identify items that were technology from 16 items presented (see Appendix A). Table 4 below shows these items, ordered by the percentage chosen as technology on the pre-assessments by EiE students. This ordering, we have found, is robust across gender, state, and ethnic differences, and we consider it to be a fair characterization of a "colloquial" understanding of what sorts of things are most and least likely to be considered "technology". The one exception to this is "Lightning", which younger children are most likely to mark as technology (because it is electrical), while older students are less likely (though still significantly likely) to mark it as such. For an extended discussion of the results from this assessment, see [2, 3].

The *Engineering is Elementary* project uses definitions from prominent proponents of engineering/technology education to inform our work with students and teachers. The International Technology Education Association (ITEA) defines technology as "…the diverse collection of processes and knowledge that people use to extend human abilities and to satisfy human needs and wants" [4]. The American Association for the Advancement of Science (AAAS), similarly, says in *Science for All Americans* that "[I]n the broadest sense, technology extends our abilities to change the world… We use technology to try to change the world to suit us better" [5]. Following these definitions, *Engineering is Elementary* considers the human-made world to be technology. Only four items on this assessment—dandelions, bird, tree, and lightning—are therefore not considered to be technology.

The seven most difficult items for students to classify as technology—cup, shoes, bandage, books, bicycle, bridge, and house—are all common items with a long history and without clearly needing electricity to run them. EiE students improved dramatically (between 39% and 53%) and significantly (McNemar Test of Symmetry $p<.000$) in their ability to correctly identify all of these human-made items as examples of technology on the post-assessment. On all of these items, students improved significantly ($p<.000$) more than the control sample. On two of these items, Bicycle and Bridge, Control students also improved significantly ($p<.001$); however control improvement was much less dramatic (13% and 10% respectively), and Control performance on the pre-assessment was also significantly lower than Test ($p<.05$).

Students tend (correctly) not to choose the natural items as examples of technology. The exception to this rule is "lightning", which was chosen by 29% of EiE students as an example of technology on the pre-assessment, and by 29% of control students on both pre- and post-assessments. An examination of the open-ended question associated with this assessment asking "How do you know if something is technology?" has shown that many students believe that technology is anything that is powered by electricity [2]. One probable reason for why so many students chose "lightning" as an example of technology is this connection to electricity. Interviews conducted in this area (not yet published) have confirmed this hypothesis. Only half as many EiE students (14%) chose lightning as technology on the post-assessment (p=.000)—performance which is significantly better than Control (p=.000).

The same open-ended question on this assessment has shown that many students believe that technology is anything "modern" or "cutting edge". This idea of technology, together with the idea that it is anything powered by electricity, explains why only about 30% or fewer students (except for EiE students on the post-assessment) choose the cup, shoes, bandage, books, bicycle, bridge, and house as examples of technology [2].

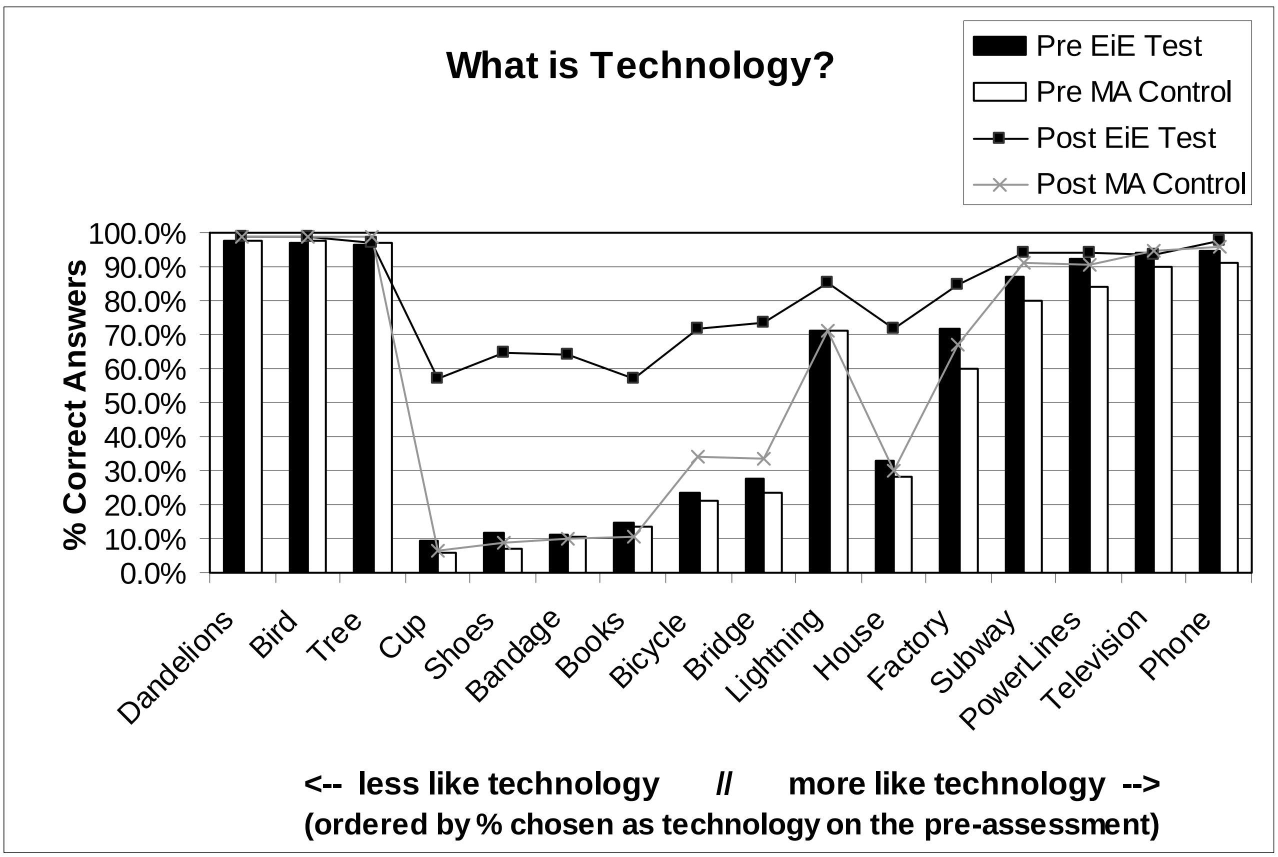


Figure 1

The following table displays significant pre- to post- differences in the percentage of correct answers within each population, as well as significant differences between the two populations. All significant differences are marked with bold type. Significant differences from pre- to post are shown in the columns marked "McNemar p=". Significant differences between the control sample and the EiE test sample are shown in the column "Test/Control Differences".

EiE showed significant improvement on all items except tree, which was rarely chosen as technology on either the pre- or post-assessment, and television, which was almost always chosen as technology on both assessments. Control students were significantly more likely to choose “television” on the post-assessment, however they were also significantly less likely than Test students to choose it on the pre-assessment. In addition to the items (bridge, bicycle, and television) discussed above, Control students also improved significantly on four more items—factory, subway, power lines, and phone (p<.01). On all of these items, Control students were significantly less likely than Test to correctly identify them as technology on both the pre-assessment (p<.001) and the post-assessment (p varies, see below).

Table 4. “What is Technology?” Assessment: EiE Test vs. MA Control									**Test/Control Differences**	
Item		**EiE Test (N=3018)**			**MA Control (N=575)**				**PRE**	**POST**
		Pre	**Post**	**McNemar p=**	**Pre**	**Post**	**McNemar p=**		**Phi p=**	**Phi p=**
↓ More like Technology / Less like Technology ↑	Dandelions*	97.5%	98.9%	**0.000**	97.6%	98.6%	0.263		0.309	0.658
	Bird*	97.0%	98.7%	**0.000**	97.6%	98.6%	0.263		0.812	0.669
	Tree*	96.6%	96.9%	0.545	96.9%	98.6%	0.064		0.256	**0.019**
	Cup	9.7%	57.1%	**0.000**	5.9%	6.6%	0.689		**0.001**	**0.000**
	Shoes	11.6%	64.6%	**0.000**	6.8%	8.9%	0.169		**0.000**	**0.000**
	Bandage	11.0%	64.1%	**0.000**	10.6%	10.3%	0.916		0.917	**0.000**
	Books	14.6%	56.9%	**0.000**	13.5%	10.9%	0.176		0.871	**0.000**
	Bicycle	23.4%	71.9%	**0.000**	20.9%	34.0%	**0.000**		**0.038**	**0.000**
	Bridge	27.8%	73.5%	**0.000**	23.7%	33.4%	**0.000**		**0.019**	**0.000**
	Lightning*	71.2%	85.6%	**0.000**	70.9%	70.9%	1.000		0.804	**0.000**
	House	33.2%	72.0%	**0.000**	28.0%	30.3%	0.397		**0.006**	**0.000**
	Factory	71.7%	85.0%	**0.000**	59.8%	67.0%	**0.007**		**0.000**	**0.000**
	Subway	87.1%	94.2%	**0.000**	79.8%	91.1%	**0.000**		**0.000**	**0.010**
	Power Lines	92.3%	93.9%	**0.015**	84.1%	90.4%	**0.001**		**0.000**	**0.001**
	Television	94.3%	93.7%	0.303	89.7%	95.0%	**0.001**		**0.000**	0.563
	Phone	94.5%	97.4%	**0.000**	91.4%	95.8%	**0.002**		**0.000**	**0.029**

*Items we scored as NOT technology

EiE student improvements were greatest on those items which they were least likely call technology on the pre-assessment—those which students show the most ambivalence about classifying as “technology” or “not technology”. This “leveling out” shows that on the post-assessment the EiE students were more likely to consistently separate natural things from human-made things in choosing which things are technologies, suggesting that they were more likely to have a canonical definition for technology. This hypothesis is corroborated by our earlier analysis of the open-ended question: on the post-assessment, EiE students were likely to answer that technology is anything “human-made”.

Not surprisingly, performance on this assessment improved with the age of the students, though the pattern and significance of improvements was almost identical for all grades. Figure 2 below displays the differences between grades 3, 4, and 5. Differences were, in all cases, less than 20%. Differences were most pronounced for the most difficult items to classify. Grades 2 and 6 were omitted from this and all future grade graphs for three reasons: for clarity (it is easier to see the trends with only three lines), because grades 2 and 6 were the least well represented, and because grade 2 and 6 tended to show the most variable performances.

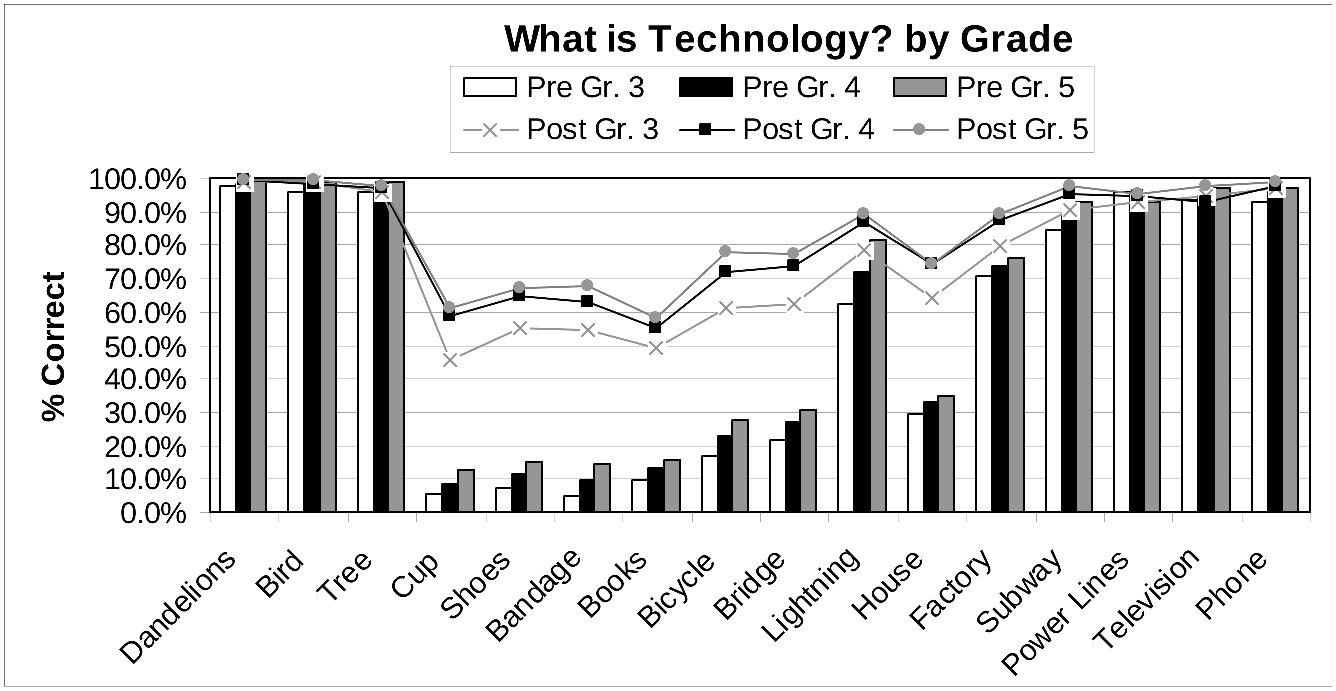


Figure 2

Table 5. "What is Technology?" Assessment: Tests for Gender Differences									**Male/Female Differences**	
Item	**Female**				**Male**				**PRE**	**POST**
	N	**Pre**	**Post**	**M. p=**	**N**	**Pre**	**Post**	**M. p=**	**Phi p=**	**Phi p=**
Dandelions*	1327	96.8%	98.8%	**0.001**	1318	98.0%	98.9%	0.099	0.170	0.863
Bird*	1327	95.7%	98.6%	**0.000**	1318	97.9%	98.6%	0.164	**0.001**	0.998
Tree*	1327	95.8%	95.9%	1.000	1317	96.9%	97.4%	0.457	0.043	**0.023**
Cup	1325	6.9%	54.4%	**0.000**	1317	11.0%	59.3%	**0.000**	**0.003**	**0.011**
Shoes	1324	8.6%	61.8%	**0.000**	1316	13.1%	66.3%	**0.000**	**0.001**	**0.010**
Bandage	1325	8.1%	60.7%	**0.000**	1318	12.6%	66.2%	**0.000**	**0.001**	**0.002**
Books	1322	12.1%	55.0%	**0.000**	1313	15.9%	57.8%	**0.000**	0.177	0.106
Bicycle	1327	18.2%	67.4%	**0.000**	1316	26.5%	75.8%	**0.000**	**0.000**	**0.000**
Bridge	1326	24.6%	72.2%	**0.000**	1318	29.0%	74.1%	**0.000**	**0.030**	0.214
Lightning*	1326	64.6%	83.1%	**0.000**	1317	74.9%	87.3%	**0.000**	**0.000**	**0.003**
House	1326	27.8%	69.9%	**0.000**	1317	36.7%	74.0%	**0.000**	**0.000**	**0.012**
Factory	1322	68.5%	84.3%	**0.000**	1318	72.8%	86.3%	**0.000**	0.228	0.147
Subway	1321	84.6%	93.0%	**0.000**	1315	89.2%	95.6%	**0.000**	**0.000**	**0.003**
Power Lines	1324	92.4%	93.1%	0.536	1315	92.1%	95.0%	**0.002**	0.371	**0.029**
Television	1327	93.3%	93.1%	0.870	1317	95.4%	94.5%	0.271	**0.015**	0.081
Phone	1326	93.2%	97.1%	**0.000**	1316	95.5%	97.9%	**0.001**	**0.000**	0.226

Gender differences for EiE (Test) students only are shown in Table 5. Both male and female students improved significantly on nearly all items. Female students improved significantly on the items "dandelions" and "bird", while male students did not. This difference is accounted for by female students' significantly lower performance on the pre-assessment (p<.001). Males performed significantly better than females on the pre-assessment, post-assessment, or both for six of the seven most difficult to classify "common technologies" (cup, shoes, bandage, bicycle, bridge, and house); the same is true for the four most commonly chosen items (subway, power lines, television, and phone). There was no significant difference between genders on the items "books" and "factory".

Table 6. "What is Technology?" Assessment: By Race/Ethnicity

Item	Race/ Ethnicity	N=	Pre	Post	M. p=	Item	Race/ Ethnicity	N=	Pre	Post	M. p=
Dandelions*	Black	225	95.6%	98.7%	.092	Bridge	Black	225	16.0%	55.6%	**.000**
	Asian	200	98.5%	98.5%	1.000		Asian	200	29.0%	79.0%	**.000**
	Hispanic	228	98.7%	99.1%	1.000		Hispanic	228	18.0%	67.5%	**.000**
	White	1156	98.0%	98.5%	.392		White	1155	27.3%	76.9%	**.000**
	Other	46	100.0%	100.0%			Other	46	21.7%	78.3%	**.000**
Bird*	Black	225	94.7%	97.8%	.118	Lightning*	Black	225	64.9%	76.4%	**.003**
	Asian	200	99.0%	99.5%	1.000		Asian	200	75.0%	86.0%	**.005**
	Hispanic	228	97.8%	98.2%	1.000		Hispanic	228	66.7%	82.9%	**.000**
	White	1156	97.2%	98.7%	**.012**		White	1155	71.6%	86.1%	**.000**
	Other	46	97.8%	97.8%	1.000		Other	46	56.5%	89.1%	**.001**
Tree*	Black	225	93.3%	96.9%	.096	House	Black	225	27.1%	57.3%	**.000**
	Asian	200	98.0%	96.5%	.508		Asian	200	33.0%	78.0%	**.000**
	Hispanic	228	96.5%	97.4%	.774		Hispanic	228	20.6%	66.7%	**.000**
	White	1155	96.8%	96.5%	.815		White	1154	32.7%	74.7%	**.000**
	Other	46	95.7%	97.8%	1.000		Other	46	26.1%	73.9%	**.000**
Cup	Black	225	7.6%	37.3%	**.000**	Factory	Black	223	67.3%	79.8%	**.001**
	Asian	200	10.0%	67.5%	**.000**		Asian	200	71.5%	85.5%	**.000**
	Hispanic	227	4.0%	44.1%	**.000**		Hispanic	228	65.8%	83.3%	**.000**
	White	1155	9.4%	61.9%	**.000**		White	1153	70.9%	87.9%	**.000**
	Other	46	8.7%	71.7%	**.000**		Other	46	84.8%	93.5%	.344
Shoes	Black	225	8.0%	40.9%	**.000**	Subway	Black	225	77.8%	93.3%	**.000**
	Asian	200	14.0%	75.5%	**.000**		Asian	200	90.5%	96.5%	**.012**
	Hispanic	228	5.7%	57.5%	**.000**		Hispanic	227	83.3%	93.4%	**.001**
	White	1153	11.6%	66.1%	**.000**		White	1155	88.9%	94.0%	**.000**
	Other	46	10.9%	71.7%	**.000**		Other	46	89.1%	97.8%	.219
Bandage	Black	225	7.1%	40.9%	**.000**	Power Lines	Black	225	90.2%	94.2%	.122
	Asian	199	13.1%	71.4%	**.000**		Asian	200	92.5%	96.0%	.167
	Hispanic	228	6.6%	54.8%	**.000**		Hispanic	227	92.5%	91.6%	.856
	White	1155	11.1%	66.9%	**.000**		White	1154	93.0%	93.8%	.485
	Other	46	8.7%	71.7%	**.000**		Other	46	95.7%	97.8%	1.000
Books	Black	225	15.6%	38.7%	**.000**	Television	Black	225	90.7%	95.6%	**.043**
	Asian	200	14.0%	63.5%	**.000**		Asian	200	96.0%	95.5%	1.000
	Hispanic	226	9.3%	46.0%	**.000**		Hispanic	227	95.6%	93.4%	.405
	White	1148	13.1%	60.4%	**.000**		White	1156	94.9%	94.1%	.452
	Other	46	13.0%	60.9%	**.000**		Other	46	93.5%	93.5%	1.000
Bicycle	Black	225	19.1%	54.2%	**.000**	Phone	Black	225	91.6%	97.3%	**.011**
	Asian	200	24.5%	79.0%	**.000**		Asian	200	96.0%	98.5%	.227
	Hispanic	228	17.5%	64.9%	**.000**		Hispanic	228	95.2%	97.8%	.210
	White	1155	23.6%	74.5%	**.000**		White	1153	95.3%	97.3%	**.013**
	Other	46	17.4%	78.3%	**.000**		Other	46	95.7%	97.8%	1.000

Table 6 shows differences for EiE (Test) students only by race/ethnicity. All groups tended to improve significantly on all but the easiest items (dandelions, bird, tree, power lines, television, phone). Significance was easies to measure for White students, because the sample size for that group was 1155 (about five times larger than any of the other groups), which probably accounts for significant improvement among white students on "bird" and "phone". Black students improved significantly on "television" and "phone", a difference which appears to be due to their lower performance on the pre-assessment for these items compared to other groups. Black and Hispanic students appear to show consistently weaker performance than White and Asian students on all of the most difficult items to classify, on both the pre- and post-assessments. As yet, we have been unable to test these differences for significance.

What is Engineering?

The "What is Engineering?" question shows 16 kinds of work and asks which are the kinds of work that engineers might do for their jobs. Two versions of this assessment were used with students. The earlier version includes more distracters; the later version includes a larger variety of engineering work to choose from (see Appendix A).

We have chosen to score these according to the definition provided by the International Technology Education Association [4], that an engineer is "A person who is trained in and uses technological and scientific knowledge to solve practical problems" (page 238)… [E]ngineers "are the innovators and designers" (page 23). According to this definition, we have chosen "arrange flowers", "sell food", and "clean teeth" as easy distracters. We have chosen "drive machines", "construct buildings", install wiring", and "repair cars" as more difficult distracters—these picture construction workers engaged in driving a log loader, riveting a steel beam, wiring an electrical junction box, and putting tires on a car. On the earlier version, "make pizza" and "teach children" were also available as easy distracters.

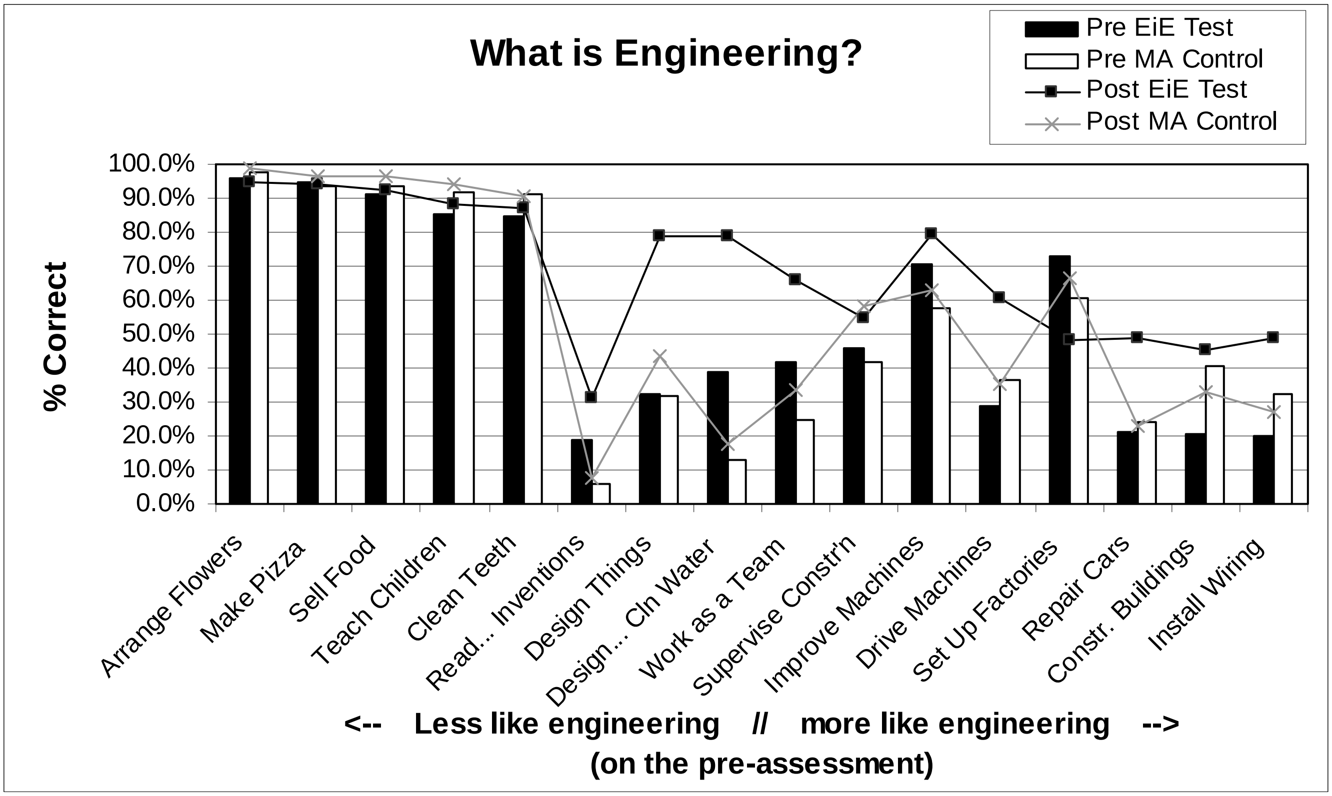


Figure 3

EiE students showed significant improvement on 15 of the 22 items (both versions combined) from pre- to post-assessment (see Figure 3 and Table 7). For 14 of these items, this improvement was dramatic (between 8% and 46% overall) and significant (p<.000). On three of the items for which a control comparison was available, the Control sample also improved; however, Control improvement was between 15% and 35% less than EiE (Test) improvement. On one item—arrange flowers—EiE students were slightly (2.2%) but significantly (p<.003) more likely to do worse on the post- than on the pre-assessment. On four items—make pizza, sell food, supervise construction and set up factories—control students showed significant improvement while EiE pre-post differences were not significant (between 0% and 7% more control students improved than test students). It is unclear why this is the case.

Table 7. "What is Engineering?" Assessment: EiE Test vs. MA Control										Test/Control Differences	
Item		EiE Test (N=2600)				MA Control (N=639)				PRE	POST
		N	Pre	Post	M. p=	N	Pre	Post	M. p=	Phi p=	Phi p=
↓ More like Engineering // Less like Engineering ↑	1.Arrange Flowers*	2600	96.2%	94.4%	**0.003**†	639	97.5%	98.6%	0.189	0.729	**0.000**
	2.Make Pizza*	170	94.7%	94.1%	1.000	639	93.3%	96.6%	**0.003**	0.734	0.077
	3.Develop Better Bubble Gum	2416	8.6%	48.7%	**0.000**						
	4.Sell Food*	2600	91.1%	92.5%	0.051	638	93.7%	96.7%	**0.013**	**0.023**	**0.000**
	5.Improve Bandages	2418	10.9%	55.7%	**0.000**						
	6.Create Warmer Kinds of Jackets	2417	13.2%	58.8%	**0.000**						
	7.Teach Children*	170	85.3%	88.2%	0.511	638	92.0%	94.2%	0.120	**0.040**	**0.007**
	8.Clean Teeth*	2599	84.6%	87.1%	**0.004**	639	91.2%	90.8%	0.828	**0.000**	**0.009**
	9.Read About Inventions	2600	18.9%	31.4%	**0.000**	638	6.0%	7.7%	0.260	**0.000**	**0.000**
	10.Figure Out How to Track Luggage	2418	27.6%	53.9%	**0.000**						
	11.Design Things	170	32.4%	78.8%	**0.000**	637	31.6%	43.3%	**0.000**	0.092	**0.000**
	12.Design Ways To Clean Water	2600	39.1%	78.7%	**0.000**	638	13.0%	17.7%	**0.018**	**0.000**	**0.000**
	13.Work As A Team	2599	41.6%	65.6%	**0.000**	637	24.8%	33.8%	**0.000**	**0.000**	**0.000**
	14.Write Computer Programs	2417	41.8%	50.2%	**0.000**						
	15.Supervise Construction	170	45.9%	54.7%	0.086	638	42.0%	58.2%	**0.000**	0.115	0.527
	16.Design Tunnels	2417	47.5%	76.0%	**0.000**						
	17.Improve Machines	170	70.6%	79.4%	0.063	638	57.5%	62.7%	**0.048**	**0.001**	**0.000**
	18.Drive Machines*	2597	29.1%	60.3%	**0.000**	638	36.4%	35.3%	0.694	**0.001**	**0.000**
	19.Set Up Factories	77	72.7%	48.1%	0.389	639	60.7%	66.7%	**0.016**	**0.004**	0.382
	20.Repair Cars*	2600	21.0%	48.8%	**0.000**	638	24.1%	22.9%	0.598	0.253	**0.000**
	21.Construct Buildings*	2598	20.5%	45.4%	**0.000**	639	40.8%	33.2%	**0.002**†	**0.000**	**0.000**
	22.Install Wiring*	2600	20.2%	48.7%	**0.000**	638	32.3%	27.3%	**0.033**†	**0.000**	**0.000**

*Items we scored as NOT Engineering. † Significant regression (p<.05)

The differences pre- to post- for EiE students are not as dramatic with the *What is Engineering?* items as for the *What is Technology?* items, but are still clear. Considerably more EiE students think that engineers might read about inventions, work as a team, design things, and design ways to clean water for their jobs after completing EiE units than beforehand. In addition, EiE students are much less likely to think that engineers would drive machines, repair cars, install wiring, or construct buildings for their jobs after completing EiE units. EiE students are much more likely to associate engineering with the design of diverse technologies on the post-assessment, and they are much less likely to associate engineering with jobs that involve engines or construction but not design.

Table 7 shows significant differences marked with bold type. Significant differences from pre- to post are shown in the rows marked “McNemar p=”. Significant differences between the control sample and the EiE test sample are shown in the column “Phi Coefficient p=”.

New items in the newer version of the *What is Engineering?* assessment were not available during Control data collection, so there is no control comparison. For all of these items, pre-post differences were highly significant according to the McNemar Test of Symmetry (p<.000). EiE students were significantly more likely on the post-assessment than on the pre-assessment to say that engineers might develop gum, improve bandages, create warmer kinds of jackets, figure out how to track luggage, write computer programs, and design tunnels for their jobs (see Figure 4). These changes show a willingness to associate engineering with the design and improvement of a broader range of technologies.

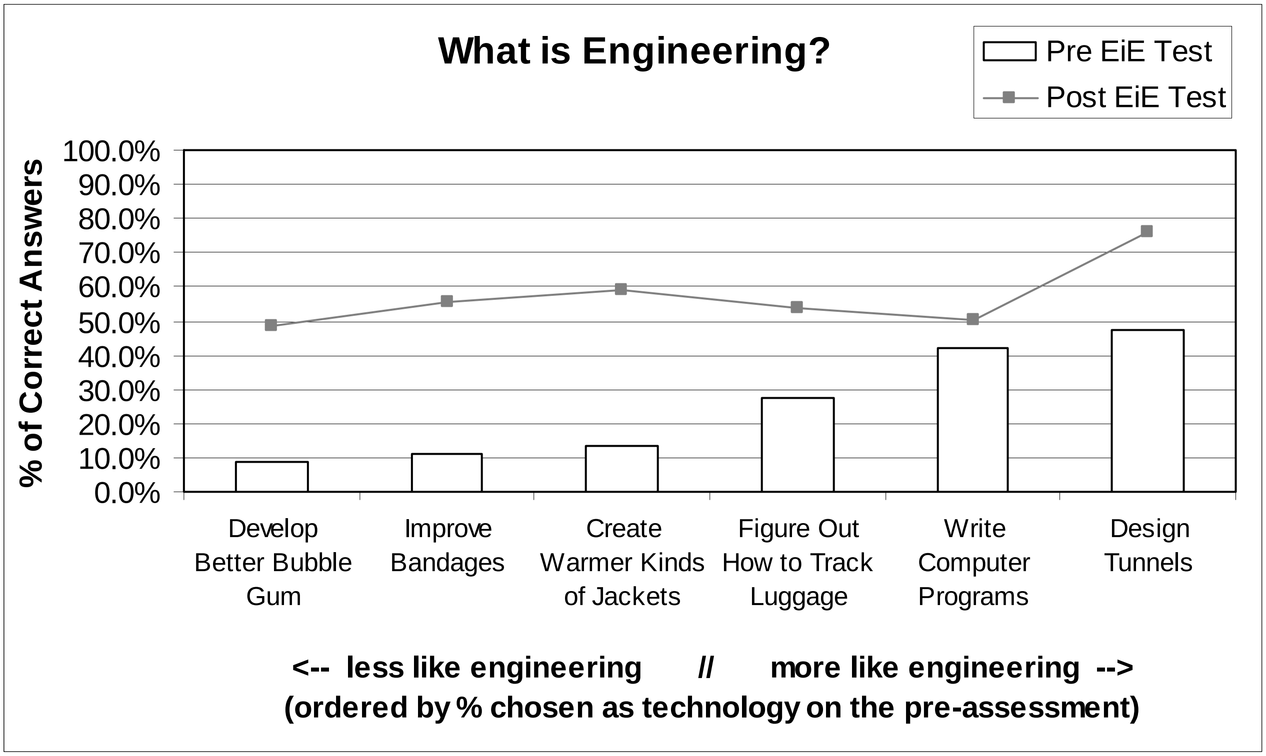


Figure 4

As with the “What is Technology?” assessment, student performance on the “What is Engineering?” assessments tended to be linked to grade, with older students performing better. Figure 5 graphs the performances of students in grade 3, 4, and 5 on the pre- and post-assessments. On all but the last three items, performance follows grade. Student performance varies by 20% at most from grade to grade.

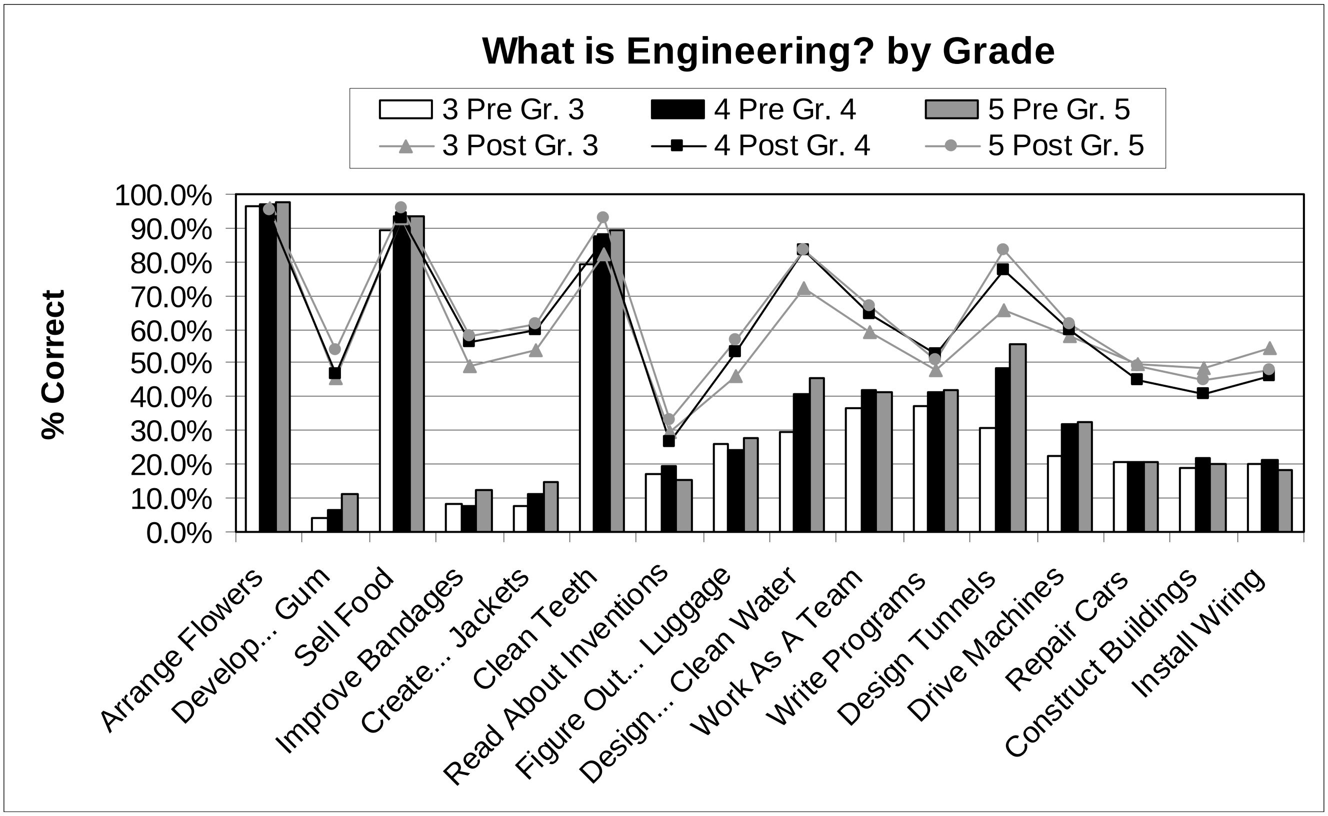


Figure 5

Unlike for the "What is Technology?" assessment, results for the "What is Engineering?" assessment are generally similar across genders. Male students were significantly more likely to correctly identify "improve bandages", "figure out how to track luggage", and "design tunnels" on the post-assessment than females, but otherwise responses were similar.

Table 8. "What is Engineering?" Assessment: Tests for Gender Differences									Male/Female Differences	
Item	**Female**				**Male**				**PRE**	**POST**
	N	**Pre**	**Post**	**M. p=**	**N**	**Pre**	**Post**	**M. p=**	**Phi p=**	**Phi p=**
1.Arrange Flowers*	1117	95.8%	95.1%	0.461	1112	96.3%	93.9%	**0.010**†	0.169	0.293
2.Make Pizza*	68	95.6%	95.6%	1.000	81	92.6%	91.4%	1.000	0.563	0.490
3.Develop Better Bubble Gum	1044	7.3%	47.1%	**0.000**	1022	8.5%	48.9%	**0.000**	0.323	0.255
4.Sell Food*	1117	90.9%	92.6%	0.127	1112	91.2%	91.6%	0.735	0.896	0.514
5.Improve Bandages	1044	9.4%	52.3%	**0.000**	1024	11.0%	57.4%	**0.000**	0.168	**0.020**
6.Create Warmer Kinds of Jackets	1044	12.9%	56.6%	**0.000**	1023	12.3%	59.8%	**0.000**	0.858	0.109
7.Teach Children*	68	82.4%	88.2%	0.454	81	87.7%	85.2%	0.815	0.097	0.540
8.Clean Teeth*	1116	84.4%	87.2%	**0.039**	1112	84.1%	85.8%	0.224	0.914	0.545
9.Read About Inventions	1117	18.9%	30.0%	**0.000**	1112	17.8%	32.7%	**0.000**	0.152	0.171
10.Figure Out How to Track Luggage	1044	26.0%	49.5%	**0.000**	1024	27.7%	56.4%	**0.000**	0.323	**0.001**
11.Design Things	68	25.0%	76.5%	**0.000**	81	29.6%	77.8%	**0.000**	0.647	0.764
12.Design Ways To Clean Water	1117	37.0%	78.1%	**0.000**	1112	39.2%	78.7%	**0.000**	0.377	0.734
13.Work As A Team	1116	41.8%	64.5%	**0.000**	1112	38.7%	65.9%	**0.000**	0.099	0.638
14.Write Computer Programs	1044	40.1%	48.9%	**0.000**	1023	40.7%	50.0%	**0.000**	0.990	0.452
15.Supervise Construction	68	45.6%	55.9%	0.248	81	49.4%	64.2%	0.058	0.803	0.376
16.Design Tunnels	1044	46.2%	73.5%	**0.000**	1023	46.9%	78.7%	**0.000**	0.262	**0.002**
17.Improve Machines	68	69.1%	76.5%	0.405	81	72.8%	81.5%	0.230	0.409	0.387
18.Drive Machines*	1116	27.5%	58.6%	**0.000**	1112	29.3%	59.1%	**0.000**	0.370	0.811
19.Set Up Factories	68	70.6%	63.2%	0.442	81	71.6%	72.8%	1.000	**0.038**	0.258
20.Repair Cars*	1117	21.6%	49.6%	**0.000**	1112	19.0%	45.7%	**0.000**	0.112	0.056
21.Construct Buildings*	1117	20.3%	43.3%	**0.000**	1110	20.8%	43.2%	**0.000**	0.778	0.949
22.Install Wiring*	1117	20.9%	48.3%	**0.000**	1112	20.2%	45.5%	**0.000**	0.742	0.247

*Items we scored as NOT Engineering. † Significant regression ($p<.05$).

The pattern of ethnic differences for the "What is Engineering?" assessment is similar to but not as pronounced as that seen for the "What is Technology?" assessment. Black and Hispanic students' performance is slightly weaker than that of Asian and White students, particularly on the pre-assessment.

Table 9. "What is Engineering?" Assessment: By Race/Ethnicity

Item	Race/ Ethnicity	N=	Pre	Post	M. p=	Item	Race/ Ethnicity	N=	Pre	Post	M. p=
1. Arrange Flowers*	Black	169	93.5%	97.0%	.210	12.Design Ways To Clean Water	Black	169	30.8%	65.1%	**0.000**
	Asian	144	95.8%	97.2%	.754		Asian	144	47.2%	81.3%	**0.000**
	Hispanic	190	98.4%	94.2%	.057		Hispanic	190	35.3%	70.5%	**0.000**
	White	875	96.3%	93.3%	**.004**†		White	875	38.4%	84.2%	**0.000**
	Other	38	89.5%	97.4%	.375		Other	38	36.8%	84.2%	**0.000**
3. Develop Better Bubble Gum	Black	159	5.0%	32.1%	**0.000**	13.Work As A Team	Black	169	34.9%	66.3%	**0.000**
	Asian	140	10.7%	49.3%	**0.000**		Asian	144	47.9%	69.4%	**0.000**
	Hispanic	174	4.6%	45.4%	**0.000**		Hispanic	190	32.1%	61.6%	**0.000**
	White	787	9.4%	49.2%	**0.000**		White	874	39.6%	67.0%	**0.000**
	Other	38	7.9%	23.7%	**0.031**		Other	38	50.0%	71.1%	0.057
4.Sell Food*	Black	169	85.8%	89.3%	0.377	14.Write Computer Programs	Black	159	34.6%	47.2%	**0.019**
	Asian	144	95.8%	95.8%	1.000		Asian	140	35.7%	45.7%	0.092
	Hispanic	190	89.5%	91.1%	0.701		Hispanic	174	42.0%	51.1%	0.085
	White	875	91.5%	92.5%	0.505		White	786	40.8%	43.4%	0.290
	Other	38	94.7%	89.5%	0.687		Other	38	44.7%	39.5%	0.774
5.Improve Bandages	Black	159	6.3%	39.6%	**0.000**	16.Design Tunnels	Black	159	37.1%	73.6%	**0.000**
	Asian	140	12.9%	54.3%	**0.000**		Asian	140	48.6%	77.1%	**0.000**
	Hispanic	174	6.9%	50.0%	**0.000**		Hispanic	174	44.3%	72.4%	**0.000**
	White	787	10.8%	57.6%	**0.000**		White	786	49.9%	80.4%	**0.000**
	Other	38	7.9%	47.4%	**0.000**		Other	38	50.0%	86.8%	**0.001**
6.Create Warmer Kinds of Jackets	Black	159	8.2%	36.5%	**0.000**	18.Drive Machines*	Black	167	29.3%	34.7%	0.336
	Asian	140	15.7%	60.0%	**0.000**		Asian	144	27.1%	66.7%	**0.000**
	Hispanic	174	9.2%	51.7%	**0.000**		Hispanic	190	27.9%	51.6%	**0.000**
	White	786	14.4%	62.2%	**0.000**		White	875	30.3%	63.4%	**0.000**
	Other	38	7.9%	44.7%	**0.000**		Other	38	7.9%	65.8%	**0.000**
8.Clean Teeth*	Black	169	76.3%	81.1%	0.268	20.Repair Cars*	Black	169	14.8%	32.5%	**0.000**
	Asian	144	86.8%	94.4%	**0.027**		Asian	144	22.9%	46.5%	**0.000**
	Hispanic	190	86.3%	84.7%	0.728		Hispanic	190	23.2%	37.4%	**0.003**
	White	875	85.4%	86.6%	0.442		White	875	22.2%	51.1%	**0.000**
	Other	38	81.6%	89.5%	0.549		Other	38	13.2%	57.9%	**0.000**
9.Read About Inventions	Black	169	14.2%	24.9%	**0.011**	21.Construct Buildings*	Black	169	24.3%	26.6%	0.694
	Asian	144	22.2%	31.3%	0.079		Asian	144	22.9%	49.3%	**0.000**
	Hispanic	190	13.2%	24.2%	**0.006**		Hispanic	190	21.1%	31.6%	**0.021**
	White	875	20.2%	31.8%	**0.000**		White	873	20.2%	44.4%	**0.000**
	Other	38	21.1%	26.3%	0.791		Other	38	7.9%	55.3%	**0.000**
10.Figure Out How to Track Luggage	Black	159	27.0%	35.8%	0.114	22.Install Wiring*	Black	169	21.3%	29.6%	0.092
	Asian	140	29.3%	47.1%	**0.001**		Asian	144	20.1%	47.9%	**0.000**
	Hispanic	174	19.5%	44.3%	**0.000**		Hispanic	190	18.4%	35.8%	**0.000**
	White	787	26.2%	56.5%	**0.000**		White	875	20.2%	49.7%	**0.000**
	Other	38	28.9%	36.8%	0.607		Other	38	18.4%	57.9%	**0.001**

Vocabulary Questions

Students were asked to correctly complete sentences with engineering vocabulary words. For all sentences, they were given a list of six words to choose from. For all vocabulary words control students performed significantly better on the post-assessment than on the pre-assessment (see Figure 6 and Table 10). EiE students improved similarly on all items, but improvement was significant from pre- to post-assessment on only three of the five items: technology, design, and engineer. Both control and EiE students improved in their use of the word "technology", but EiE students performed significantly better on the post-assessment than control students (p<.011).

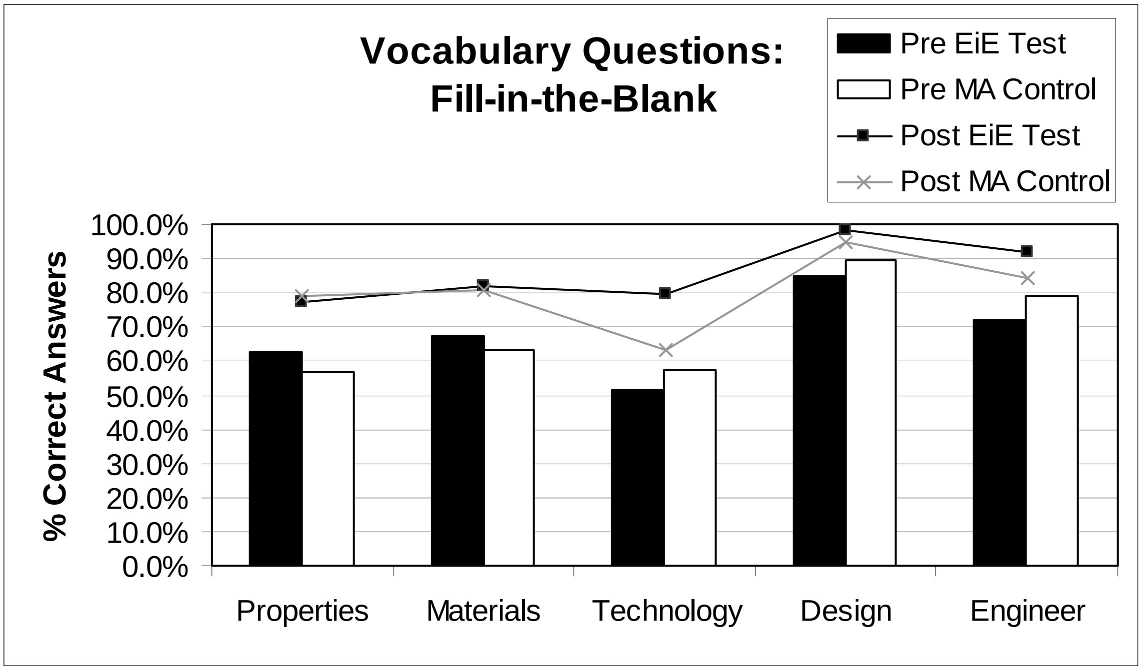


Figure 6

Table 10. Vocabulary Questions: Fill-in-the-Blank									**Test/Control Differences**	
	EiE Test				**MA Control**				**PRE**	**POST**
Vocab. Item	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
Properties	61	62.3%	77.0%	0.108	648	56.9%	78.9%	**0.000**	0.929	0.598
Materials	61	67.2%	82.0%	0.108	652	63.2%	81.0%	**0.000**	0.900	0.950
Technology	58	51.7%	79.3%	**0.002**	647	57.5%	63.4%	**0.020**	0.997	**0.011**
Design	60	85.0%	98.3%	**0.021**	650	89.7%	94.6%	**0.001**	**0.035**	0.188
Engineer	61	72.1%	91.8%	**0.004**	647	78.8%	84.1%	**0.003**	0.621	0.179

A newer version of the vocabulary assessment, using the same sentences with blanks for completion, was designed to be multiple-choice (see Appendix A). For each sentence, students were given three words to choose from. EiE students were significantly more likely (p=.000) to choose the correct vocabulary word on the post-assessment than on the pre-assessment (see Figure 7 and Table 11). Control students did not receive these questions so there is no comparison available.

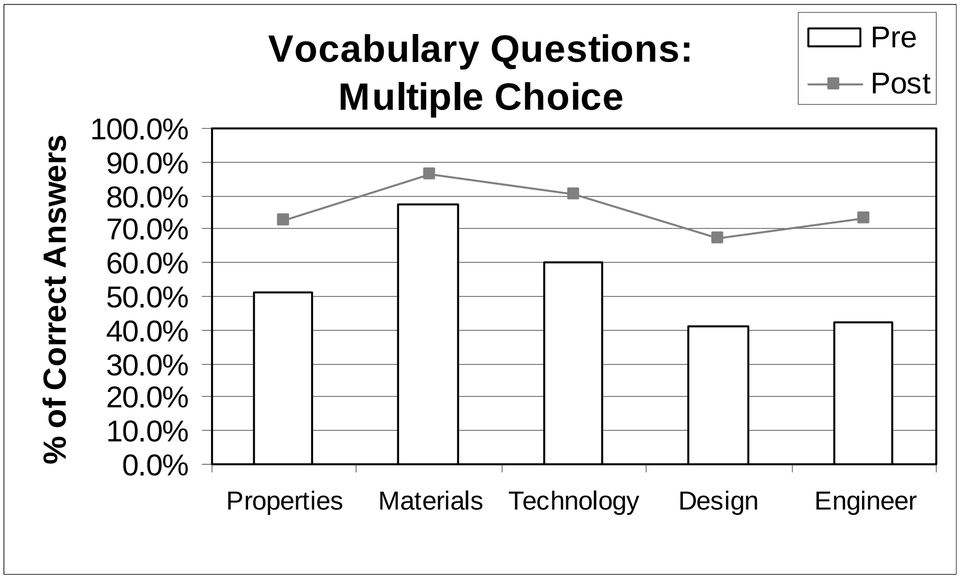


Figure 7

Table 11 also shows results broken out by grade. Only grades 4 and 5 are shown; the sample sizes for grades 2 and 3 were too small to analyze (grade 2 N=39; grade 3 N=34). Both grades 4 and 5 showed significant improvement on all questions. Evidence for this being simply a maturation effect, however, is strong for the first three items: the grade 4 performance on the post-assessment is roughly equivalent to the grade 5 performance on the pre-assessment. This pattern does not hold for the items “design” and “engineer”.

The revised vocabulary questions, which were multiple-choice questions instead of chosen from a common list, appear to be more difficult for students to answer correctly—only “technology” and “materials” were correctly identified as frequently or more frequently than in the original version. However, EiE students improved much more dramatically on this version of the assessment than on the original.

Table 11. Vocabulary Questions: Multiple Choice		**N=**	**Pre**	**Post**	**McNemar p=**
Properties	Total	439	51.3%	72.9%	**0.000**
	Grade 4	181	38.7%	68.0%	**0.000**
	Grade 5	187	73.8%	86.1%	**0.001**
Materials	Total	445	77.3%	86.3%	**0.000**
	Grade 4	184	70.1%	88.0%	**0.000**
	Grade 5	188	83.5%	93.1%	**0.002**
Technology	Total	442	60.2%	80.5%	**0.000**
	Grade 4	183	53.6%	73.2%	**0.000**
	Grade 5	186	71.5%	91.9%	**0.000**
Design	Total	446	41.3%	67.5%	**0.000**
	Grade 4	184	33.2%	64.1%	**0.000**
	Grade 5	190	55.8%	81.1%	**0.000**
Engineer	Total	447	42.5%	72.9%	**0.000**
	Grade 4	183	36.1%	66.1%	**0.000**
	Grade 5	191	56.0%	85.9%	**0.000**

Table 12 shows the results for analysis of gender differences on the multiple-choice version of the vocabulary assessment. Results are similar for all questions, except that female students were significantly more likely to choose the correct answer for the “engineer” question than male students on the post-assessment.

Table 12. Multiple Choice Vocabulary Questions: Tests for Gender Differences									**Male/Female Differences**	
	Female				**Male**				**PRE**	**POST**
Vocab. Item	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
Properties	224	52.2%	73.2%	**0.000**	211	49.8%	72.5%	**0.000**	0.842	0.441
Materials	223	75.8%	88.8%	**0.000**	218	79.4%	83.5%	0.262	0.698	0.201
Technology	221	62.0%	78.7%	**0.000**	217	57.6%	82.0%	**0.000**	0.245	0.445
Design	223	38.6%	70.0%	**0.000**	219	44.3%	65.8%	**0.000**	0.065	0.228
Engineer	223	41.3%	78.5%	**0.000**	220	44.1%	67.3%	**0.000**	0.443	**0.013**

Questions about the Engineering Design Process

We asked the EiE students a series of questions about the engineering design process (see Appendix A). Each question presented a scenario where children were designing something, and asked which step of the engineering design process those children were engaged in, or would be engaged in next. In one case, the question asked about the materials children were discussing for their design. On all questions except question 6, EiE students were significantly more likely to choose the correct answers on the post-assessment than on the pre-assessment (see Figure 8 and Table 13).

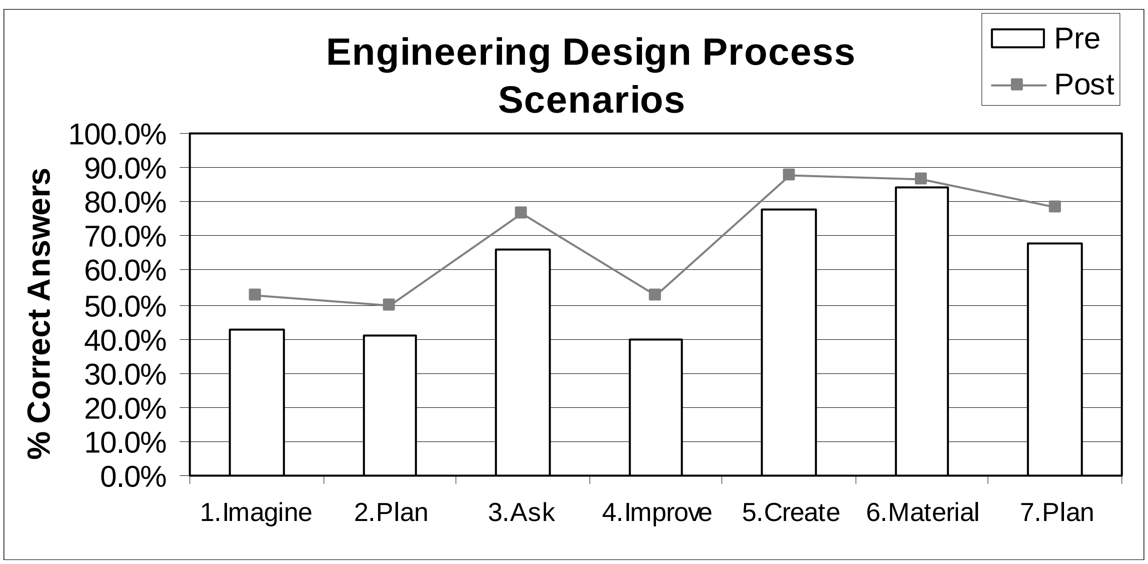


Figure 8

Again, the analysis is broken out by grade. Grade 3 students (N=36) answered questions 3, 4, 5 but the analysis of their responses was not completed because of the small sample size. Grade 2 students were asked only questions 6 and 7.

Grades 4 and 5 responded similarly to questions 1 and 4; both grades improved significantly. Only grade 5 students improved significantly on question 2 (p<.01). On questions 3 and 5, both grades 4 and 5 improved significantly, but the grade 4 response rates on the post-assessment were closest to the grade 5 response rates on the pre-assessments. On question 7, only grade 4 improved significantly, but grade 4 students were less likely to answer the pre-assessment correctly, while grades 4 and 5 performed similarly on the post-assessment. Grades 2 and 3 in all cases were not as likely to answer correctly as older students. Grade 3 students improved significantly on question 4 only. The pattern of results shows that much of the improvement, particularly at the lower grades where students are learning to read, may be due to maturation effects. A control sample will be necessary to confirm or deny this hypothesis.

Table 13. Engineering Design Process Scenarios		**N=**	**Pre**	**Post**	**McNemar p=**
1. Yi Min and Chen were talking about how to mix earth materials to make a strong mortar. [2 ideas] …They continued to think of more ideas. Which step of the EDP do you think Yi Min and Chen were working on? [Imagine]	Total	470	42.8%	52.8%	**0.001**
	Grade 4	178	42.1%	53.9%	**0.017**
	Grade 5	256	45.3%	55.9%	**0.013**
2. What step of the Engineering Design Process would Yi Min and Chen do next? [Plan]	Total	429	41.0%	49.9%	**0.009**
	Grade 4	176	42.6%	44.9%	0.731
	Grade 5	217	40.6%	57.1%	**0.001**
3. Antoine and Sara are working on a design. They are making this list. Which step of the EDP are they working on? [Ask]	Total	467	66.0%	76.7%	**0.000**
	Grade 4	177	59.3%	71.8%	**0.005**
	Grade 5	254	71.7%	80.7%	**0.010**
4. David and Sonali are working on a design. They are making this list. Which step of the engineering design process are they working on? [Improve]	Total	422	40.0%	52.6%	**0.000**
	Grade 3	105	28.6%	41.9%	**0.044**
	Grade 4	162	42.0%	55.6%	**0.009**
	Grade 5	155	45.8%	56.8%	**0.040**
5. Dana and Leif were building a small windmill together. The two of them attached the blades to the rotor and it began to spin. Which step… were they working on? [Create]	Total	423	77.5%	87.5%	**0.000**
	Grade 3	105	67.6%	75.2%	0.256
	Grade 4	163	76.1%	89.0%	**0.001**
	Grade 5	155	85.8%	94.2%	**0.011**
6. Maria and Bobby designed a chair that they wanted to make. Bobby suggested making it out of wood. Maria wanted to use plastic or metal. What are Maria and Bobby talking about? [Material for the chair]	Total	451	84.5%	86.7%	0.373
	Grade 2	81	84.0%	85.2%	1.000
	Grade 3	70	84.3%	74.3%	0.210
	Grade 4	147	85.0%	89.8%	0.248
	Grade 5	153	84.3%	90.2%	0.175
7. Caitlin and Faith are working on a design. They are making this list and drawing. Which step of the engineering design process are they working on? [Plan]	Total	463	67.6%	78.4%	**0.000**
	Grade 2	96	56.3%	75.0%	**0.004**
	Grade 3	68	42.6%	51.5%	0.307
	Grade 4	147	73.5%	84.4%	**0.017**
	Grade 5	152	80.3%	86.8%	0.132

Table 14 shows gender differences for the engineering design process scenarios. Female students were more likely to improve significantly than males on four of the seven questions. On all of these questions, gender differences on the pre-assessment were insignificant, but gender differences on the post-assessment were significant ($p<.05$), confirming that female students were more likely to improve on these questions than male students. An interesting avenue for further research would be whether this is due to the type of question (scenarios) being better suited to the interest and/or aptitudes of female students, or whether female students identified more strongly with the engineering design process as presented in the EiE units and storybooks.

Table 14. Engineering Design Process Scenarios: Tests for Gender Differences									Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	232	45.7%	54.7%	**0.038**	234	38.9%	51.3%	**0.005**	0.070	0.284
2	214	43.9%	54.2%	**0.032**	211	37.9%	46.0%	0.114	0.439	**0.049**
3	231	66.2%	82.3%	**0.000**	232	66.4%	71.1%	0.254	0.092	**0.002**
4	209	36.8%	59.8%	**0.000**	206	43.7%	46.1%	0.653	0.948	**0.006**
5	210	78.6%	88.6%	**0.002**	206	75.7%	86.4%	**0.005**	0.803	0.294
6	229	85.2%	92.6%	**0.016**	218	83.9%	81.2%	0.497	0.651	**0.001**
7	236	68.6%	81.8%	**0.000**	223	66.4%	75.3%	**0.022**	0.165	0.174

Summary of the General Engineering and Technology Assessment Results

EiE students improved significantly and dramatically on all “What is Technology?” and “What is Engineering?” items. Their performance was dramatically better than control on the post-assessment. EiE students improved significantly from pre- to post- on the majority of vocabulary and engineering design process questions, and performed somewhat better than control on multiple-choice vocabulary questions.

Males tended to do better on the “What is Technology?” assessment than females; their performance was much closer to equivalent on the “What is Engineering?” assessment, though males still tended to perform better. Females performed slightly better than males on the vocabulary assessment, and much better than males on the engineering design process scenarios.

White and Asian students tended to perform better than Black and Latino students on the “What is Technology?” and “What is Engineering?” items; however these differences have not been measured for significance.

Results for the Designing Water Filters Unit Questions

Students participating in the *Designing Water Filters* EiE curriculum unit learned about environmental engineering and the design of water filters. They identified pollutants in a series of pictures of typical American neighborhood scenes (Lesson 2), they tested a variety of materials for filtering particulates and chemicals from water (Lesson 3), and they designed their own water filters (Lesson 4).

On the pre- and post-assessments these students were asked a variety of questions about water filters, water filter materials, and environmental engineering. They were also asked a series of science questions about water. EiE students performed significantly better on the post-assessment than they did on the pre-assessment for nearly all of these questions.

Designing Water Filters Unit: Questions with Control Comparison

Four questions were given to both EiE (test) and control samples. The text for these questions is given in Table 15. It is important to note that the control sample for question 1 was drawn from the Massachusetts control sample, while control samples for questions 2 and 7 were drawn from EiE control (students who completed an EiE unit other than *Designing Water Filters*). The control sample for question 3 included students from both samples.

Table 15. Designing Water Filters Unit: Assessment Questions with Control Comparison (Text)	
Question #	**Question Text**
1	(MCAS) At 10AM the Sun is shining on a puddle of water on the road. At 2PM the Sun is still shining and the puddle has disappeared. What happened to the water? [it evaporated]
2	Some people in your town want to use water from a lake for drinking water. They need to check the water… What would NOT make the water unsafe for drinking? [twigs, leaves, and dirt]
3	On a hot day, Damon poured himself a glass of cold lemonade. A few minutes later, his glass was wet and slippery on the outside. How did the water get there? [it condensed]
7	Julia wants to make a net to pull bugs, leaves, and dirt out of her pool. She made a handle for her net. Which material would be BEST to use for the middle of the net? [a piece of cloth]

Analysis for questions 2, 3, and 7 is given in Table 16. The assessment results were also broken out and analyzed by grade for grades 3, 4, and 5. Grade 6 test assessments (N=33) were not analyzed due to the small sample size; nor were grade 2 assessments (question 2 test N=22; control N=86; question 3 test N=23; control N=111; question 7 test N=40; control N=115).

Neither sample improved significantly on question 1, which was taken from the 1998 Massachusetts Comprehensive Assessment System (MCAS) in Science and Technology/Engineering [6]. This question asked students about the water cycle (evaporation). Both test and control students found this question relatively easy, with 87% or more answering correctly on the pre-assessment as well as the post-assessment.

Table 16. Designing Water Filters Unit: Assessment Questions										Test / Control Differences	
		EiE Test				Control				PRE	POST
Q#	Group	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	Total	61	86.9	93.4	0.289	228	92.1	96.1	0.108	0.206	0.382
2	Total	830	25.7	45.8	**0.000**	579	24.9	41.5	**0.000**	0.736	0.122
	Grade 3	109	24.8	23.9	1.000	128	23.4	61.7	**0.000**	0.866	**0.000**
	Grade 4	313	23.6	34.5	**0.001**	213	25.4	39.4	**0.001**	0.703	0.240
	Grade 5	353	23.8	60.1	**0.000**	152	30.9	25.0	0.222	0.084	**0.000**
3	Total	1256	48.7	61.2	**0.000**	612	55.7	66.0	**0.000**	**0.005**	0.051
	Grade 3	205	31.2	42.0	**0.007**	131	45.0	64.9	**0.001**	**0.009**	**0.000**
	Grade 4	452	48.9	57.5	**0.002**	217	67.3	74.2	0.053	**0.000**	**0.000**
	Grade 5	543	53.2	71.6	**0.000**	153	73.9	73.2	1.000	**0.000**	0.721
7	Total	1223	58.5%	73.5%	**0.000**	391	63.4	68.0	0.168	0.083	**0.026**
	Grade 3	176	46.0%	55.1%	0.056	66	65.2	56.1	0.377	**0.008**	0.855
	Grade 4	422	56.6%	75.1%	**0.000**	131	71.0	74.0	0.644	**0.004**	0.752
	Grade 5	552	61.1%	77.0%	**0.000**	79	65.8	72.2	0.487	0.410	0.354

Both test and control improved significantly (p<.001) on question 2, which asked about water contaminants. There were no significant differences overall between test and control on the pre- or the post-assessment. Both test and control students in grade 4 improved significantly (p<.01) and similarly on this question. However, EiE (test) students in grade 5 improved significantly (p<.001) and better than control on the post-assessment (p<.001), while grade 3 control students improved significantly (p<.001) and better than test on the post-assessment (p<.001). In fact, grade 3 control students performed better than any other grade group on the post-assessment (61.7% correct); it is unclear why this is the case.

Question 3 again asked about the water cycle (condensation). On this question, control students performed significantly (p<.01) better than test on the pre-assessment both overall and in all grades, indicating that these samples were probably not well matched. Both test and control improved significantly (p<.001), but overall there was no significant difference between them on the post-assessment. Looking more closely at performance by grade, EiE students at all grades improved significantly (p<.01), while only grade 3 control students improved significantly (p<.01). Still, control performance on the pre-assessment was so much higher than test performance, that even an insignificant improvement (grade 4) for control resulted in significantly (p<.001) better performance on the post-assessment for grades 3 and 4. It is unknown why control did so much better on this question on the pre-assessment.

EiE (test) students improved significantly (p<.001) on question 7 (grades 4 and 5 improved significantly, p<.001), while control students did not (overall or at any grade). Test students also performed significantly better on the post-assessment than control students (p<.05) overall, but not when broken out by grade.

Among the EiE (test) students, students in grades 4 and 5 improved significantly on all questions, while grade 3 students improved significantly on question 3 only. The large number of significant differences between test and control on the pre-assessment call into question the suitability of test-control comparison on this assessment, or the reliability of the questions. Further analysis will be necessary to determine the factors relevant to these outcomes.

Designing Water Filters Unit: Engineering Questions without Control Comparison

EiE students were asked eight questions about water filters and water filter materials, one of which was already discussed (question 7). On all of questions 4 through 6c but two (5a and 6a), students were significantly (p<.001) more likely to answer correctly on the post-assessment than on the pre-assessment (see Table 17). These results held up for grades 4 and 5 as well; grade 3 improved on questions 4, 6b, and 6c. The two questions asking about sand as a filter material did not show significant pre-post changes, which may reflect students' mixed results using this material in the classroom. Results for questions asking about other filter materials—paper and screen—were dramatically improved, as were results for the question asking about methods for cleaning water (students were much more likely on the post-assessment to correctly mark the distracter, "use soap", as NOT a way to clean water).

Question #4:

Which of the following is NOT a way to make water cleaner? Circle **ONE** answer.

A. Add soap.

B. Add a little chlorine.

C. Shine ultraviolet light on it.

D. Pour it through a sand filter.

Table 17. Designing Water Filters Unit: Assessment Questions		N=	Pre	Post	McNemar p=
4. Which of the following is NOT a way to make water cleaner? [Add soap]	Total	410	37.6%	70.2%	**0.000**
	Grade 3	93	25.8%	39.8%	**0.029**
	Grade 4	132	34.1%	74.2%	**0.000**
	Grade 5	185	45.9%	82.7%	**0.000**
5a. If you want to build a filter that gets leaves out of water, should you use [a] sand filter? [Yes]	Total	412	42.2%	41.0%	0.764
	Grade 3	93	32.3%	37.6%	0.458
	Grade 4	132	43.9%	34.8%	0.119
	Grade 5	187	46.0%	47.1%	0.920
5b. If you want to build a filter that gets leaves out of water, should you use [a] paper filter? [Yes]	Total	413	46.0%	71.4%	**0.000**
	Grade 3	93	48.4%	57.0%	0.185
	Grade 4	132	43.9%	67.4%	**0.000**
	Grade 5	188	46.3%	81.4%	**0.000**
5c. If you want to build a filter that gets leaves out of water, should you use metal screen? [Yes]	Total	412	67.0%	79.1%	**0.000**
	Grade 3	93	61.3%	64.5%	0.664
	Grade 4	132	62.9%	82.6%	**0.000**
	Grade 5	187	72.7%	84.0%	**0.008**
6a. If you want to build a filter that gets flour out of water, should you use [a] sand filter? [Yes]	Total	412	63.1%	60.9%	0.543
	Grade 3	93	53.8%	51.6%	0.856
	Grade 4	131	61.8%	51.1%	0.109
	Grade 5	188	68.6%	72.3%	0.494
6b. If you want to build a filter that gets flour out of water, should you use [a] paper filter? [Yes]	Total	413	40.7%	78.5%	**0.000**
	Grade 3	93	37.6%	58.1%	**0.003**
	Grade 4	132	37.9%	81.8%	**0.000**
	Grade 5	188	44.1%	86.2%	**0.000**
6c. If you want to build a filter that gets flour out of water, should you use metal screen? [No]	Total	413	63.4%	83.1%	**0.000**
	Grade 3	93	61.3%	74.2%	**0.029**
	Grade 4	132	63.6%	89.4%	**0.000**
	Grade 5	188	64.4%	83.0%	**0.000**

Questions 5 and 6 in particular are nearly direct assessments of what students were learning in the *Designing Water Filters* unit: students filtered out soil and corn starch, not leaves and flour, but they did test sand, paper, and screen as filter materials. Questions 4 and 7 ask about similar situations to what they were learning in the unit, but are not directly drawn from what students were doing. Student ambivalence about questions 5a and 6a is evidence of problems with the unit, which we have addressed: the sand provided to students in kits was in some cases too fine—instead of filtering out materials, it was stirred up by the filtering process and came through with the water (and contaminants) being filtered. Student improvement on questions 4 and 7 show that students are transferring what they learned to new though similar situations.

EiE students were also asked questions (8a-8d) about the kinds of work done by environmental engineers (see Table 18 and Figure 10). Three of the four questions showed significant improvement ($p<.001$); the fourth (question 8d) was easy for students (>80% correct both pre- and post- for all students). Looking at the data by grade, grade 3 students improved significantly on 8b and 8c, grade 4 students improved significantly on 8a, and grade 5 students improved significantly on 8a and 8b—8c appeared to be too easy for grade 5 students (>85% correct on both pre- and post-assessments), making it more difficult to see improvement. Only 17 grade 2 students answered question 8: too few for analysis.

Table 18. Designing Water Filters Unit: Assessment Questions		N=	Pre	Post	McNemar p=
8a. Nathan is an environment engineer. Check ALL of the things that Nathan might do for his job: Stop harmful plants from growing in a lake. [Yes]	Total	433	59.6%	72.7%	**0.000**
	Grade 3	94	46.8%	46.8%	1.000
	Grade 4	131	48.9%	71.0%	**0.000**
	Grade 5	191	72.3%	85.9%	**0.001**
8b. Nathan is an environment engineer. Check ALL of the things that Nathan might do for his job: Rescue dolphins from fishing nets. [No]	Total	434	54.6%	68.0%	**0.000**
	Grade 3	94	50.0%	69.1%	**0.001**
	Grade 4	131	59.5%	67.9%	0.152
	Grade 5	192	54.7%	68.8%	**0.001**
8c. Nathan is an environment engineer. Check ALL of the things that Nathan might do for his job: Decide methods for cleaning air. [Yes]	Total	433	75.1%	85.2%	**0.000**
	Grade 3	94	55.3%	77.7%	**0.001**
	Grade 4	131	77.1%	83.2%	0.215
	Grade 5	191	84.3%	89.0%	0.163
8d. Nathan is an environment engineer. Check ALL of the things that Nathan might do for his job: Sort river rocks by size. [No]	Total	433	87.5%	89.4%	0.434
	Grade 3	94	80.9%	85.1%	0.557
	Grade 4	130	86.2%	81.5%	0.377
	Grade 5	192	91.7%	95.8%	0.115
9a. Check ALL of the things that could add pollutants to the air: Car. [Yes]	Total	434	84.1%	91.0%	**0.000**
	Grade 3	94	51.1%	73.4%	**0.000**
	Grade 4	132	90.9%	91.7%	1.000
	Grade 5	191	95.3%	98.4%	0.070
9b. Check ALL of the things that could add pollutants to the air: Dog. [Yes]	Total	434	11.3%	17.5%	**0.001**
	Grade 3	94	12.8%	11.7%	1.000
	Grade 4	132	6.1%	9.7%	**0.035**
	Grade 5	191	11.0%	20.9%	**0.001**
9c. Check ALL of the things that could add pollutants to the air: Waterfall. [No]	Total	435	90.1%	93.8%	**0.023**
	Grade 3	94	75.5%	89.4%	**0.004**
	Grade 4	132	93.2%	91.7%	0.791
	Grade 5	192	95.3%	97.9%	0.180
9d. Check ALL of the things that could add pollutants to the air: Factory. [Yes]	Total	433	95.6%	97.9%	0.064
	Grade 3	94	87.2%	94.7%	0.118
	Grade 4	131	96.9%	96.9%	1.000
	Grade 5	191	99.0%	100.0%	**-**

The work of environmental engineers is described in the storybook that sets the context for the unit: the main character's mother is an environmental engineer, and the child describes her mother's work for the students. The work of environmental engineers is also discussed in the context of identifying pollutants in the environment in lesson 2 of the unit. Students do not make a list or otherwise enumerate or memorize the sorts of things environmental engineers do for their work, but through contextual experience with examples of what engineers do, they are able to extrapolate to the related examples in the assessment—their answers improve significantly on the post-assessment.

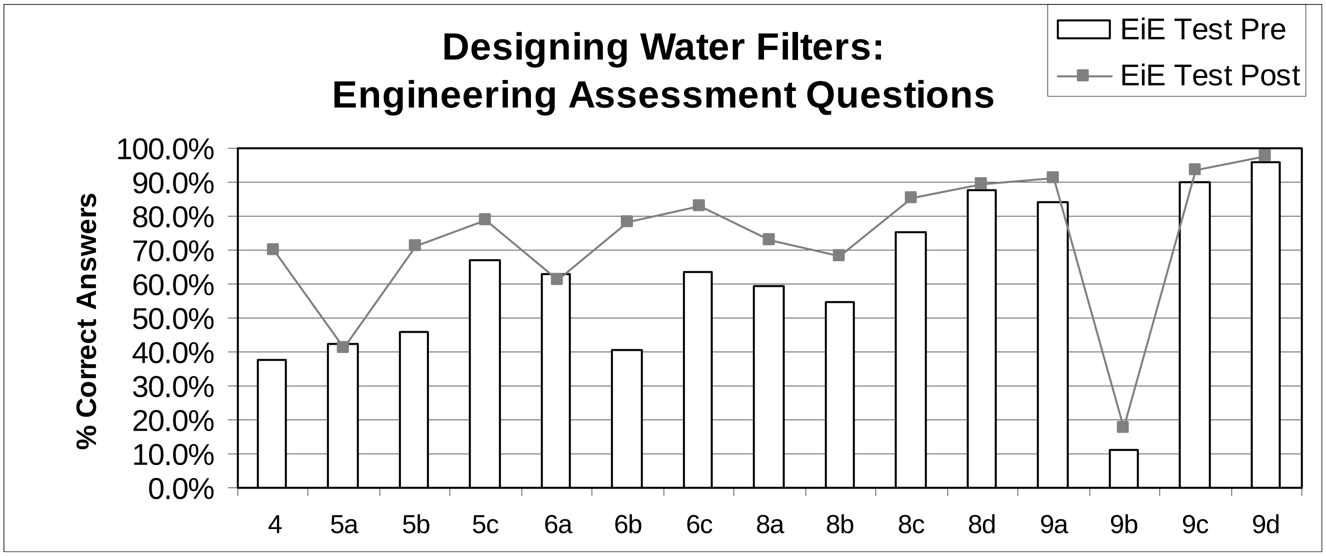


Figure 9

Questions 9a-9d asked about items that might contribute pollutants to the air. Three of the four questions about pollutants (#'s 9a-9c) showed significant improvement ($p<.01$) The fourth (9c) showed a ceiling effect (both pre- and post-assessments >95%). Question 9b was dropped from the assessment because the answer could be argued as either true or false: dogs do in fact release methane, which students learn about in the lesson, but in very tiny amounts.

The grade-level differences on question 9 are instructive. Only grades 4 and 5 improved significantly on question 9b (a dog could add pollutants). Only grade 3 students improved correctly on questions 9a and 9c, while grade 4 and 5 students showed a ceiling effect on these questions (both pre- and post-assessments >90%). The fact that students find the questions about pollutants easy to answer correctly on both the pre- and post-assessment suggests that older students may need a more challenging lesson on the topics provided than is currently presented in the unit.

Designing Water Filters Unit: Science Content Questions without Control Comparison

The remaining six questions for the Water Filters unit are science content questions (Table 19). EiE students showed significant improvement on three of these questions. Of the three which did not show improvement, question 10c ("True or False: Water disappears forever when it evaporates") appears to have been too easy for students (nearly 87% of students answered the pre-assessment correctly) and so is showing a ceiling effect. Question 10a ("True or False: Earth has limited fresh water") showed a slight and not significant regression (fewer students answered correctly on the post-assessment). This probably reflects a poorly worded question (if you think about the generation of new fresh water over time through the water cycle, then Earth ultimately has unlimited fresh water). The question has been revised for future assessments.

Currently we are working to collect control data on these science questions from classrooms where students are learning the science of water, but not using the *Designing Water Filters* unit. Teachers have told the EiE curriculum development team that students learn the science better when they apply it to an engineering design challenge, but as yet we have no statistical evidence of this. By comparing students who study the science only with those who study both the science and the engineering, we hope to find a definitive answer to this question.

Table 19. Designing Water Filters Unit: Assessment Questions		N=	Pre	Post	McNemar p=
10a. The Earth has a limited amount of fresh water. [Scored as True—question dropped.]	Total	415	58.1%	55.7%	0.407
	Grade 3	95	36.8%	41.1%	0.585
	Grade 4	128	51.6%	57.0%	0.311
	Grade 5	192	72.9%	62.0%	**0.005**
10b. Condensation is part of the water cycle. [True]	Total	416	77.9%	84.4%	**0.012**
	Grade 3	95	71.6%	62.1%	0.175
	Grade 4	129	67.4%	91.5%	**0.000**
	Grade 5	192	88.0%	90.6%	0.442
10c. Water disappears forever when it evaporates. [False]	Total	418	87.8%	89.5%	0.470
	Grade 3	96	82.3%	81.3%	1.000
	Grade 4	130	84.6%	86.9%	0.701
	Grade 5	192	92.7%	95.3%	0.359
10d. The water cycle makes new water. [False]	Total	417	39.6%	49.2%	**0.001**
	Grade 3	96	40.6%	35.4%	0.487
	Grade 4	129	34.9%	51.2%	**0.005**
	Grade 5	192	42.2%	54.7%	**0.001**
10e. If polluted water freezes, it is no longer contaminated. [False]	Total	415	74.7%	79.8%	0.062
	Grade 3	93	69.9%	66.7%	0.711
	Grade 4	130	69.2%	84.6%	**0.002**
	Grade 5	192	80.7%	82.8%	0.659
10f. Water can be a solid, liquid, or gas. [True]	Total	416	73.3%	84.4%	**0.000**
	Grade 3	95	72.6%	66.3%	0.362
	Grade 4	129	58.1%	84.5%	**0.000**
	Grade 5	192	83.9%	93.2%	**0.001**

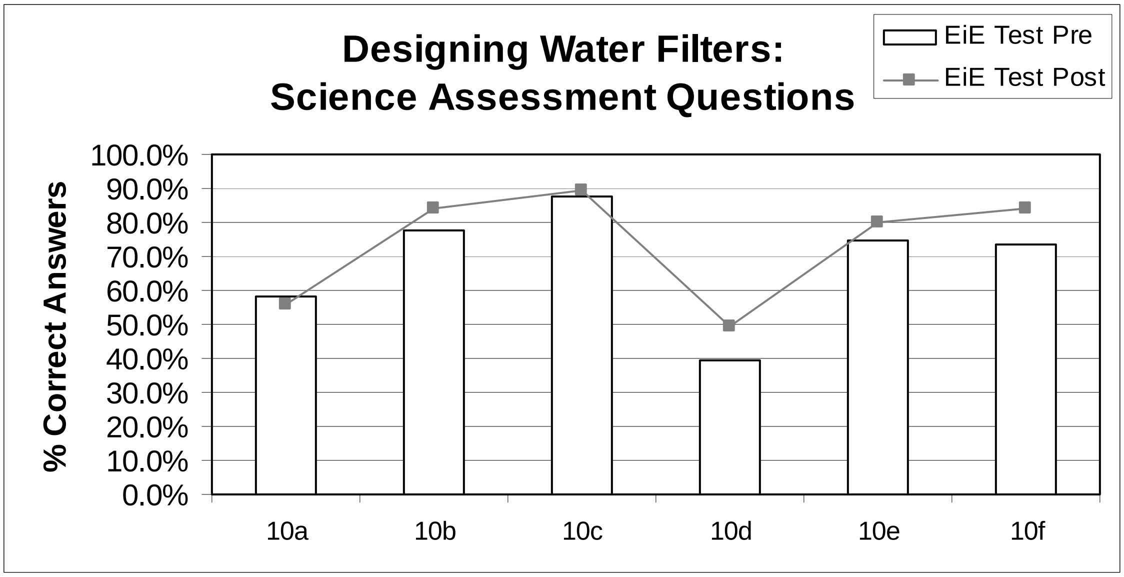


Figure 10

Designing Water Filters Unit: Gender and Race/Ethnicity Differences

There were very few significant differences between males and females on any of the *Designing Water Filters* assessment questions (Table 20). Female students did significantly ($p<.01$) better than males on the pre-assessment for question 4, which asked about ways to make water cleaner. Females also did significantly better on both the pre-assessment (p<.05) and the post-assessment (p<.01) for question 8d, asking whether an environmental engineer would sort river rocks for his job. Male students did significantly (p<.05) better than females on the pre-assessment for question 10d, which was a science true/false question about the water cycle. Females improved significantly on this question (p<.01), while males did not.

Table 20. Designing Water Filters Unit: Tests for Gender Differences									**Male / Female Differences**	
	Female				**Male**				**PRE**	**POST**
Q#	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
2	370	24.6%	43.2%	**0.000**	355	23.7%	43.9%	**0.000**	0.837	0.770
3	592	45.6%	58.3%	**0.000**	554	48.7%	61.9%	**0.000**	0.265	0.222
4	215	45.6%	74.0%	**0.000**	193	28.0%	65.8%	**0.000**	**0.001**	0.080
5a	216	42.6%	37.0%	0.261	194	42.3%	45.4%	0.576	0.779	0.050
5b	216	46.3%	73.6%	**0.000**	195	45.6%	69.2%	**0.000**	0.824	0.379
5c	216	67.6%	80.1%	**0.001**	194	66.5%	77.8%	**0.006**	0.923	0.487
6a	215	62.3%	61.4%	0.915	195	64.1%	60.0%	0.445	0.635	0.950
6b	216	41.2%	78.7%	**0.000**	195	40.0%	78.5%	**0.000**	0.675	0.820
6c	216	62.5%	80.6%	**0.000**	195	64.6%	86.2%	**0.004**	0.705	0.149
7	573	57.6%	71.4%	**0.000**	540	57.0%	74.1%	**0.000**	0.806	0.251
8a	221	62.0%	73.3%	**0.005**	210	57.1%	72.4%	**0.000**	0.370	0.965
8b	222	50.9%	64.0%	**0.001**	210	58.1%	72.4%	**0.000**	0.141	0.071
8c	222	76.6%	86.5%	**0.003**	209	73.2%	84.2%	**0.004**	0.363	0.543
8d	222	91.0%	93.2%	0.473	209	84.2%	85.2%	0.885	**0.041**	**0.005**
9a	223	84.8%	91.9%	**0.001**	209	83.3%	90.4%	**0.008**	0.640	0.673
9b	222	13.5%	17.6%	0.163	210	9.0%	17.6%	**0.002**	0.172	1.000
9c	223	89.7%	94.6%	0.061	210	90.5%	93.3%	0.180	0.861	0.542
9d	222	95.9%	97.3%	0.581	209	95.2%	98.6%	0.065	0.737	0.245
10a	217	57.1%	53.0%	0.342	196	59.2%	58.2%	0.883	0.744	0.350
10b	215	75.8%	83.3%	0.052	199	80.4%	85.4%	0.184	0.214	0.500
10c	217	87.6%	88.9%	0.720	199	88.9%	89.9%	0.868	0.595	0.878
10d	216	34.7%	45.8%	**0.009**	199	45.2%	53.3%	0.052	**0.028**	0.147
10e	215	74.4%	80.0%	0.148	198	75.3%	79.3%	0.350	0.913	0.730
10f	215	71.6%	83.7%	**0.000**	199	75.4%	84.9%	**0.009**	0.452	0.886

Due to limitations on the significance test for multiple non-parametric categories, we are still seeking a way to test differences across racial/ethnic groups. On the *Designing Water Filters* assessment (see Table 21), White students improved significantly about twice as often as the other groups, but this is very likely because the sample size for White students is about five times as large as that of the other groups (making the test more sensitive). All groups tended to improve on the questions, but the subgroup of Asian students most frequently had the highest percentage of correct answers when looking across all pre-assessments (13 of 24 questions, or 54.2%) as well as on the post-assessments (18.5/24, or 77.0%). The subgroup of Black students most frequently showed the lowest percentage correct across pre-assessments (10/24 or 41.7%) and post-assessments (17/24 or 70.8%).

Race/ethnicity is strongly correlated with region; each region represented in the sample has its own standards for science and its own methods for teaching science/engineering/technology. Further analysis will be necessary to determine the variables relevant to differences in performance across subgroups.

Table 21. Designing Water Filters Unit: Tests for Differences by Race / Ethnicity

Race / Ethnicity	Q#	N	Pre	Post	McNemar p=	Q#	N	Pre	Post	McNemar p=
Black	2	73	20.5	38.4	**0.019**	8c	58	58.6	81.0	**0.011**
Asian		60	38.3	53.3	0.150		50	82.0	92.0	0.125
Latino		95	22.1	56.8	**0.000**		46	56.5	76.1	**0.022**
White		220	20.0	38.6	**0.000**		266	79.3	86.8	**0.017**
Black	3	134	44.0	46.3	0.780	8d	58	84.5	79.3	0.629
Asian		110	44.5	64.5	**0.001**		51	80.4	92.2	0.109
Latino		139	34.5	55.4	**0.000**		46	84.8	87.0	1.000
White		469	50.3	64.0	**0.000**		265	90.2	90.9	0.875
Black	4	59	28.8	44.1	0.064	9a	58	53.4	74.1	**0.004**
Asian		51	41.2	78.5	**0.000**		50	92.0	96.0	0.625
Latino		45	20.0	62.2	**0.000**		46	69.6	87.0	**0.021**
White		242	42.6	76.4	**0.000**		267	91.0	94.0	0.134
Black	5a	59	33.9	42.4	0.383	9b	58	19.0	20.7	1.000
Asian		51	47.1	49.0	1.000		51	7.8	15.7	0.219
Latino		45	33.3	31.1	1.000		46	10.9	15.2	0.500
White		244	44.7	41.0	0.452		266	10.9	18.0	**0.007**
Black	5b	59	45.8	64.4	**0.027**	9c	58	74.1	89.7	**0.022**
Asian		51	58.8	76.5	0.078		51	100.0	96.1	-
Latino		45	48.9	68.9	**0.049**		46	78.3	91.3	0.070
White		245	43.3	73.1	**0.000**		267	93.3	94.8	0.503
Black	5c	59	64.4	66.1	1.000	9d	58	89.7	93.1	0.727
Asian		51	64.7	80.4	0.115		51	98.0	96.1	1.000
Latino		45	53.3	55.6	1.000		45	91.1	100.0	-
White		245	71.0	86.1	**0.000**		267	97.0	98.9	0.180
Black	6a	59	64.4	47.5	0.064	10a	58	43.1	39.7	0.824
Asian		51	68.6	76.5	0.481		50	72.0	66.0	0.581
Latino		45	62.2	51.1	0.359		46	56.5	56.5	1.000
White		244	62.7	62.3	1.000		248	59.7	57.7	0.620
Black	6b	59	30.5	67.8	**0.000**	10b	58	75.9	67.2	0.405
Asian		51	37.3	82.4	**0.000**		50	86.0	98.0	0.070
Latino		45	42.2	66.7	**0.013**		46	82.6	73.9	0.388
White		245	43.3	82.4	**0.000**		249	77.5	86.7	**0.003**
Black	6c	59	57.6	69.5	0.143	10c	58	77.6	67.2	0.263
Asian		51	62.7	90.2	**0.004**		50	94.0	94.0	1.000
Latino		45	73.3	75.6	1.000		47	93.6	91.5	1.000
White		245	63.7	85.3	**0.000**		250	89.2	93.2	0.110
Black	7	131	51.9	61.1	0.148	10d	58	41.4	36.2	0.678
Asian		108	48.1	78.7	**0.000**		50	38.0	60.0	**0.013**
Latino		134	53.7	69.4	**0.003**		47	38.3	31.9	0.581
White		473	59.2	74.6	**0.000**		250	39.6	52.8	**0.000**
Black	8a	58	53.4	58.6	0.581	10e	57	75.4	68.4	0.503
Asian		51	62.7	86.3	**0.008**		50	72.0	82.0	0.302
Latino		45	44.4	62.2	0.077		46	63.0	73.9	0.332
White		266	62.8	75.9	**0.001**		249	77.5	82.3	0.148
Black	8b	58	53.4	77.6	**0.003**	10f	58	67.2	67.2	1.000
Asian		51	58.8	78.4	**0.006**		50	82.0	96.0	**0.039**
Latino		46	58.7	65.2	0.581		47	61.7	74.5	0.210
White		266	53.8	63.9	**0.006**		248	75.8	87.9	**0.000**

Summary of the Designing Water Filters Results

EiE students performed better than control on one of three questions where control comparison was available. EiE students improved significantly from pre- to post- on the majority of engineering and science questions. There were few significant differences between genders on the *Designing Water Filters* assessment, with females showing slightly better performance in most cases where there were differences. White and Asian students performed better than Black and Latino students, however it is unclear whether this is more due to regional differences or racial differences.

Results for the Designing Walls Unit Questions

The EiE curriculum unit *Designing Walls* focuses on the design of mortar for use in building walls. As "materials engineers", students learn about the properties of materials and how those properties affect how they can be used in designs (Lesson 2). They test three different kinds of earth materials for stickiness when wet and after drying (Lesson 3), and they construct sample walls using the mortar they design and test them to failure (Lesson 4).

Designing Walls Unit Questions

On the pre- and post-assessments for year 2 and year 3 of the EiE project, students were asked three questions (text shown in Table 22; analysis in Table 23). These questions were given to EiE (test) students who completed the *Designing Walls* unit, to 47 students in grade 2 who did not complete any EiE unit (control), and to EiE students who did not complete the *Designing Walls* unit (EiE control).

Table 22. Designing Walls Unit: Assessment Questions (Text)

Question #	Question Text
1	(MCAS) Gavin has two rocks. Both are the same kind of rock. What property of his two rocks is most likely to be the same?
2	(MCAS) Soil is a mixture of many substances. It may include:
3	Ben wants to build a path through his father's garden. What earth material would make a path that is easy to walk on and does not get slippery when wet?

The first question was drawn from the 2003 MCAS [7], and asks about properties of earth materials. Understanding of the concepts of properties and materials are primary goals of Lesson 2, and a secondary focus of Lesson 3. Both test and control students improved significantly on this question, with control students performing significantly better on the pre-assessment ($p<.01$) and test students performing significantly better on the post-assessment ($p<.001$). The grade 2 and grade 4 test subsamples improved significantly on this item, as did the grade 5 control subsample. Only the grade 2 students showed significantly different performance, and only on the post-assessment, with test students much more likely to answer correctly ($p<.01$).

Question 2 is an MCAS question which asks about the composition of soil [6]. The composition of soil and properties of earth materials in particular are the primary focus of Lesson 3. Again, both test and control students improved significantly ($p<.001$) on this question. Differences on the post-assessments between the two samples were insignificant; grade 2 control students (all MA control) were much more likely to answer this question correctly on the pre-assessment than test. Grade 3 and 4 students (both test and control) improved significantly without significant differences between them; grade 5 control students also improved significantly while test did not, however test students were much more likely to answer this question correctly on the pre-assessment.

Question #3 asks about the use of earth materials in an application (a garden path). Again, related content was the subject of Lesson 3 of the unit. EiE test students improved significantly on this question (p<.01), while control students did not. Grade 2 test students were the only subgroup to show significant improvement.

A new version of the *Designing Walls* unit assessment is currently being tested and consists of more questions.

Table 23. Designing Walls Unit: Assessment Questions											**Test / Control Differences**	
		EiE Test				**EiE Control**					**PRE**	**POST**
Q#	**Group**	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**		**Phi p=**	**Phi p=**
1	Total	538	62.1%	75.5%	**0.000**	376	64.1%	73.9%	**0.001**		**0.001**	**0.000**
	Grade 2	103	45.6%	63.1%	**0.011**	47	36.2%	36.2%	1.000		0.277	**0.002**
	Grade 3	54	63.0%	66.7%	0.791	60	55.0%	63.3%	0.442		0.388	0.812
	Grade 4	301	65.1%	81.4%	**0.000**	42	71.4%	76.2%	0.740		0.435	0.504
	Grade 5	39	69.2%	82.1%	0.267	190	65.8%	77.4%	**0.008**		0.552	0.519
	Grade 6	41	73.2%	68.3%	0.774	84	63.1%	72.6%	0.096		0.263	0.676
2	Total	542	29.0%	58.1%	**0.000**	377	36.9%	62.1%	**0.000**		**0.028**	0.451
	Grade 2	104	8.7%	49.0%	**0.000**	46	39.1%	60.9%	0.110		**0.000**	0.149
	Grade 3	55	10.9%	25.5%	**0.021**	60	21.7%	41.7%	**0.012**		0.121	0.067
	Grade 4	303	34.3%	69.3%	**0.000**	42	31.0%	61.9%	**0.007**		0.637	0.343
	Grade 5	38	55.3%	57.9%	1.000	191	36.6%	68.1%	**0.000**		**0.024**	0.161
	Grade 6	42	40.5%	42.9%	1.000	84	51.2%	63.1%	0.076		0.256	**0.031**
3	Total	510	48.2%	56.1%	**0.007**	375	56.5%	60.8%	0.224		0.066	0.195
	Grade 2	104	35.6%	58.7%	**0.002**	45	51.1%	62.2%	0.267		0.069	0.505
	Grade 3	52	38.5%	44.2%	0.678	59	37.3%	44.1%	0.557		0.978	0.864
	Grade 4	274	52.2%	58.0%	0.141	42	73.8%	61.9%	0.359		**0.011**	0.582
	Grade 5	38	68.4%	57.9%	0.481	190	55.3%	63.2%	0.115		0.118	0.502
	Grade 6	42	47.6%	50.0%	1.000	84	64.3%	66.7%	0.851		0.073	0.070

Gender Differences on the Designing Walls Assessments

There was only one difference between genders on the *Designing Walls* assessments (Table 24); male students were significantly more likely to answer question 2 (about the composition of soil) correctly on the post-assessment than females (p<.05). Both male and female students improved significantly on all questions. The analysis of racial/ethnic differences was not run because of insufficient numbers of subjects in the subsamples.

Table 24. Designing Walls Unit: Tests for Gender Differences									Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	209	56.9%	76.1%	**0.000**	215	63.3%	78.1%	**0.000**	0.185	0.733
2	211	25.6%	55.0%	**0.000**	216	31.0%	64.8%	**0.000**	0.206	**0.046**
3	197	44.7%	55.8%	**0.026**	197	50.8%	61.4%	**0.029**	0.228	0.224

Summary of the Designing Walls Results

EiE students improved somewhat better than control on all of the *Designing Walls* assessment questions. Male students did better on the post-assessment than females for one of three questions, but otherwise performance was statistically the same.

Results for the Designing Bridges Unit Questions

Students participating in the *Designing Bridges* EiE curriculum unit learn about civil engineering and the design of bridges. In Lesson 2, they identify pushes and pulls as two kinds of forces. In Lessons 3 and 4, students first test three varieties of paper bridges for structural strength; they then design their own bridges of paper, string, and other simple materials to span several feet.

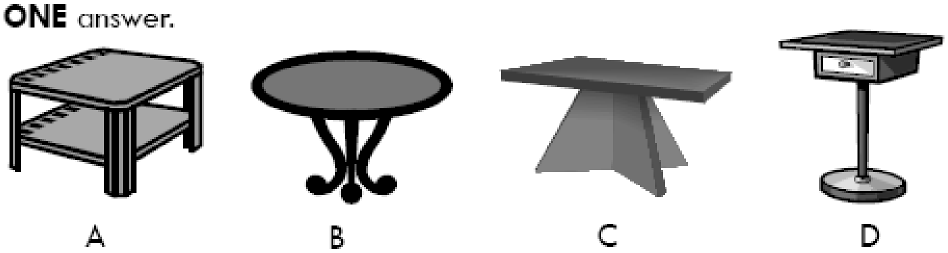
In the pre- and post-assessments students were asked a variety of questions about bridges, structural strength, and structural stability. EiE students performed significantly better on the post-assessment than they did on the pre-assessment on all but one of the questions. Unfortunately the control sample size for the *Designing Bridges* unit was too small to be used for statistical analysis; reporting is done for the EiE sample only (see Table 25). Thirty-six grade 3 students participated in this assessment, but their results were not analyzed as a subgroup because of the small sample size.

Designing Bridges Unit Questions

Question 1 was reproduced from the Massachusetts Comprehensive Assessment System (MCAS) [8] and was given only to Massachusetts students. This question asked which of four brackets would be best to use to hold a bicycle; only one of the bracket pairs pictured shows functional bracing. The 74 students answering this question did not show statistical improvement.

Question #2:

Tara wants to design a table to hold her family's television.
What shape of table is strongest and least likely to tip over? Circle **ONE** answer.



Question 2 presented pictures of four tables and asked which was the most stable. EiE students were significantly more likely to answer this question correctly on the post-assessment than on the pre-assessment (P<.001). EiE students overall improved significantly on this question (p<.01); students in grades 2, 4, and 5 all improved significantly (p<.05). Students in grade 6 did not improve, but their scores on both pre- and post-assessment were both over 90%, so a ceiling effect is likely. Structural stability is a key focus of the bridges unit.

Four more questions were introduced on the national assessment in year 3 of the EiE project. These four were designed to replace the MCAS questions which had been given to Massachusetts field and control students in year 2 of the project. Question 4 asks students to indicate which of four choices would be best to improve a beam bridge, while questions 5a, 5b, and 5c were three parts of a single question asking students to match pictures of bridges to the correct names for those bridge types (arch, beam, and suspension bridges). Students were significantly more likely to correctly answer these questions on the post-assessment than they were on the pre-assessment (p<.001). These results held up for all grade subgroups, except grade 5 students did not improve significantly on question 5c (identify the beam bridge).

Table 25. Designing Bridges Unit: Assessment Questions		**N=**	**Pre**	**Post**	**McNemar p=**
1. (MCAS) Jamie wants to put a rack on the wall to store his bicycle. Which pair of brackets below would do the best job of holding the bicycle? [D shows angled bracing]	Total	74	62.2	71.6	0.265
2. Tara wants to design a table to hold her family's television. What shape of table is strongest and least likely to tip over? [A shows a table with four widely-spaced legs]	Total	577	77.8	84.2	**0.002**
	Grade 2	112	60.7	71.4	**0.043**
	Grade 4	133	76.7	87.2	**0.016**
	Grade 5	177	76.8	86.4	**0.027**
	Grade 6	119	96.6	92.4	0.180
4. 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]	Total	559	67.8	83.2	**0.000**
	Grade 2	92	44.6	69.6	**0.000**
	Grade 4	135	67.4	88.9	**0.000**
	Grade 5	177	67.8	79.1	**0.009**
	Grade 6	119	87.4	95.0	**0.012**
5a. What kinds of bridges are these? Draw lines to the correct names. [suspension bridge]	Total	539	51.4	78.5	**0.000**
	Grade 2	87	39.1	74.7	**0.000**
	Grade 4	133	57.9	93.2	**0.000**
	Grade 5	170	53.5	69.4	**0.001**
	Grade 6	115	55.7	82.6	**0.000**
5b. What kinds of bridges are these? Draw lines to the correct names. [arch bridge]	Total	541	58.4	80.8	**0.000**
	Grade 2	87	39.1	79.3	**0.000**
	Grade 4	133	66.9	91.7	**0.000**
	Grade 5	170	57.1	68.2	**0.020**
	Grade 6	116	69.0	92.2	**0.000**
5c. What kinds of bridges are these? Draw lines to the correct names. [beam bridge]	Total	539	75.3	85.5	**0.000**
	Grade 2	86	70.9	86.0	**0.024**
	Grade 4	133	84.2	96.2	**0.002**
	Grade 5	170	72.4	77.6	0.262
	Grade 6	115	78.3	87.8	**0.043**

Question #4:

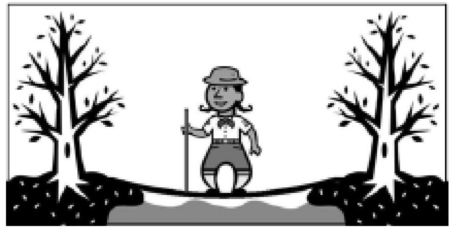
. Maria placed a board across a stream to make a bridge, but her bridge sagged when she stood on it. What should she do to improve her bridge? Choose the **BEST** answer.

A. support the ends

B. support the middle

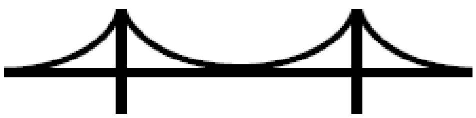
C. put some cardboard on top

D. use cardboard instead of wood

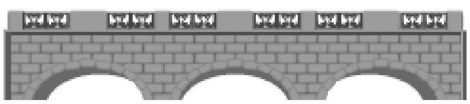


Question Items 5a-5c

. What kinds of bridges are these? Draw lines to the correct names.



Arch Bridge



Beam Bridge

Suspension Bridge

Gender Differences on the Designing Bridges Assessments

Both male and female students improved significantly on all assessment questions (Table 26). There were no significant differences between genders.

Table 26. Designing Bridges Unit: Tests for Gender Differences									**Male / Female Differences**	
	Female				**Male**				**PRE**	**POST**
Q#	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
2	288	74.0%	83.0%	**0.004**	287	76.3%	85.0%	**0.005**	0.549	0.499
4	250	63.2%	81.2%	**0.000**	247	71.3%	83.8%	**0.000**	0.054	0.363
5a	238	48.3%	74.8%	**0.000**	239	56.1%	81.2%	**0.000**	0.063	0.198
5b	241	57.3%	78.4%	**0.000**	238	60.9%	82.4%	**0.000**	0.328	0.605
5c	240	71.7%	81.7%	**0.006**	237	78.1%	88.2%	**0.003**	0.083	0.188

Summary of the Designing Bridges Results

EiE students improved significantly, and often dramatically, on all of the *Designing Bridges* assessment questions. Male and female student results were statistically the same.

Results for the Designing Windmills Unit Questions

Students participating in the *Designing Windmills* EiE curriculum unit learned about mechanical engineering and the design of windmills and wind turbines. In lesson 2, they examined various machines and their moving parts, seeing how the machines transformed the direction of force. In lesson 3, they designed sails for a “boat”, and for the culminating lesson, they designed small windmills that could lift weights (do work).

On the pre- and post-assessments these students were asked a variety of questions about windmill design, wind energy, technologies using the wind, and mechanical engineering. EiE students performed significantly better on the post-assessment than they did on the pre-assessment on 12 of 15 questions. However, where a control sample was available, EiE (test) students performed no better than the EiE control sample.

Designing Windmills Unit: Questions with Control Comparison

The text for the eight questions for which control comparison is available is given in Table 27. The test sample is about four times larger than control, and includes larger proportions of grade 2 students (23% test vs. 13% control) and grade 5 students (43% vs. 19%). However, only question 3a showed significant differences between control and test on the pre-assessment, evidence that these differences had a minor effect on the total population comparisons. The control sample was drawn from students who completed at least one EiE unit but not the *Designing Windmills* unit. Results are given in Table 28.

Question #1 asked students to choose which of four items would not show how hard the wind is blowing. Students found this particular question very difficult: only 15% answered correctly on the pre-assessment. Both test ($p<.001$) and control ($p<.05$) improved significantly on this question; there was no significant difference between test and control on either the pre- or the post-assessment. The specific content of this question is only addressed in the storybook (Lesson 1). EiE (test) students in grades 2 ($p<.05$) and 5 ($p<.001$) improved significantly on this question. Students in grades 3 and 4 did not improve significantly.

Table 27. Designing Windmills Unit: Assessment Questions (Text)

Question #	Question Text
1	Which of the following does NOT show how hard the wind is blowing? Circle ONE answer. [a weather vane]
3a	Some technologies use the energy of the wind. Circle the technologies that use the energy of the wind: glider. [yes]
3b	Circle the technologies that use the energy of the wind: weather vane. [yes]
3c	Circle the technologies that use the energy of the wind: sailing ship. [yes]
3d	Circle the technologies that use the energy of the wind: space shuttle. [yes—dropped]
3e	Circle the technologies that use the energy of the wind: computer. [no]
3f	Circle the technologies that use the energy of the wind: kite. [yes]
3g	Circle the technologies that use the energy of the wind: rocket. [no]

Table 28. Designing Windmills Unit: Technologies Using the Wind										Test / Control Differences	
		EiE Test				EiE Control				PRE	POST
Q#	Group	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	Total	1077	15.0	24.1	**0.000**	299	15.1	21.1	**0.036**	0.919	0.249
	Grade 2	164	18.9	30.5	**0.014**	37					
	Grade 3	133	15.0	13.5	0.856	48	16.7	10.4	0.549	0.937	0.740
	Grade 4	244	15.6	13.5	0.500	156	10.9	17.9	0.080	0.173	0.227
	Grade 5	501	11.8	27.7	**0.000**	58	17.2	15.5	1.000	0.224	0.072
3a	Total	1200	67.5	76.8	**0.000**	306	59.5	74.8	**0.000**	**0.006**	0.488
	Grade 2	270	60.0	73.0	**0.001**	40					
	Grade 3	138	60.9	71.0	0.081	50	50.0	74.0	**0.012**	0.188	0.688
	Grade 4	246	71.1	78.5	**0.022**	157	65.0	73.9	0.081	0.170	0.322
	Grade 5	510	69.8	78.6	**0.000**	59	55.9	67.8	0.092	**0.029**	0.058
3b	Total	1201	86.0	89.7	**0.003**	306	86.3	93.8	**0.001**	0.906	**0.041**
	Grade 2	270	76.7	87.4	**0.001**	40					
	Grade 3	138	83.3	87.0	0.383	50	88.0	92.0	0.754	0.392	0.342
	Grade 4	247	88.7	91.5	0.265	157	86.0	94.9	**0.004**	0.524	0.303
	Grade 5	510	89.6	90.2	0.832	59	93.2	93.2	1.000	0.384	0.430
3c	Total	1200	85.4	92.6	**0.000**	306	86.6	95.1	**0.000**	0.625	0.183
	Grade 2	270	72.2	89.6	**0.000**	40					
	Grade 3	138	81.9	84.8	0.503	50	82.0	94.0	0.109	0.929	0.094
	Grade 4	246	88.6	91.9	0.229	157	89.2	94.9	0.108	0.840	0.372
	Grade 5	510	91.0	96.1	**0.001**	59	93.2	94.9	1.000	0.568	0.665
3d	Total	827	12.2	11.2	0.554	248	10.5	9.3	0.701	0.521	0.489
	Grade 2	254	18.9	14.6	0.200	40					
	Grade 3	98	15.3	14.3	1.000	50	18.0	12.0	0.549	0.777	0.700
	Grade 4	110	10.9	16.4	0.286	157	6.4	6.4	1.000	0.250	**0.017**
	Grade 5	329	6.7	6.4	1.000	41					
3e	Total	1202	96.7	95.8	0.302	306	97.4	99.0	0.227	0.722	**0.017**
	Grade 2	271	96.3	93.7	0.230	40					
	Grade 3	138	95.7	93.5	0.581	50	98.0	100.0	-	0.461	0.064
	Grade 4	247	97.2	95.5	0.344	157	97.5	98.7	0.687	0.852	0.174
	Grade 5	510	97.1	97.8	0.557	59	100.0	98.3	-	0.182	0.817
3f	Total	1202	90.3	94.0	**0.000**	306	89.9	96.7	**0.000**	0.795	0.102
	Grade 2	271	84.9	91.5	**0.020**	40					
	Grade 3	138	80.4	90.6	**0.007**	50	84.0	100.0	-	0.536	**0.024**
	Grade 4	247	93.5	92.3	0.701	157	93.0	96.2	0.267	0.980	0.198
	Grade 5	510	93.9	96.9	**0.032**	59	94.9	93.2	1.000	0.763	0.149
3g	Total	373	81.8	83.6	0.435	58	86.2	89.7	0.774	0.374	0.246

For question 3, students were asked to identify technologies using the wind from a set of 6 pictures ("Rocket"—#3g — replaced "Space Shuttle" —#3d — on a later version of the assessment, because the space shuttle functions as a glider sometimes and as a rocket at other times, so this item was deemed confusing and dropped). On four of the seven items, both test and control students were significantly more likely to answer correctly on the post-assessment than on the pre-assessment ($p<.001$ except 3b $p<.01$). More than two-thirds of all students answered these four items correctly on the pre-assessment—these were relatively easy items. Among test students, all grade 2 subgroups improved significantly on the four questions (3a and 3b: $p<.01$; 3c: $p<.001$; 3f: $p<.05$). Grade 3 improved significantly on question 3f ($p<.01$); grade 4 improved significantly on question 3a ($p<.05$); and grade 5 improved significantly on questions 3a ($p<.001$), 3c ($p<.001$), and 3f ($p<.05$). Among control student subgroups, grade 2 improved significantly on question 3a ($p<.05$) and grade 4 improved significantly on question 3b ($p<.01$).

Three other items did not show significant improvement. "Computer" (3e) was too easy—96% or more of students answered correctly on both pre- and post-assessments—and "Space Shuttle" (3d), as explained above, was dropped from the survey as a poor item. "Rocket", the replacement item for "Space Shuttle", also did not show improvement.

In general, performance on question 3 both pre- and post- showed insignificant differences between test and control; however test students performed significantly better on the pre-assessment of question 3a, while control students performed significantly better on the post-assessment for questions 3b and 3e.

Designing Windmills Unit: Questions without Control Comparison

Seven more questions were administered only to EiE (test) students in grades 2 through 5 (Table 29). However, sample sizes in grade 2 (N=17) and grade 3 (N=40) were too small for subgroup analysis.

Question 2 was drawn from the 2003 MCAS [7] and asks about how to find the direction of the wind. Only 90 grade 2 students from Massachusetts completed this question. Students improved 14%, which was significant ($p<.01$).

Question items 4a-4d are "choose all that apply" items for a question asking students to indicate how they could improve a windmill. This question draws upon what students should have learned in Lesson 4 from designing their own windmills. EiE students improved significantly on all four choices ($p<.001$ except 4b $p<.01$). The grade 4 and grade 5 subgroups both improved significantly on item 4a (grade 4: $p<.01$; grade 5: $p<.001$) and item 4d ($p<.001$); grade 5 students improved significantly on 4c as well ($p<.01$).

Question 5 asks students to make the connection between wind energy and two technologies, windmills and sailboats. Though this was one of the easier questions (75% of students answered correctly on the pre-assessment), students were still 8% more likely to answer correctly on the post-assessment ($p<.01$). Grade 5 students improved significantly on this question ($p<.05$) but not grade 4 students.

Question 5:

Windmills and sailboats:

A. make wind.

B. use wind energy.

C. use solar energy.

D. don't need energy to move.

The final question (question 6) asks students about the work of mechanical engineers. Students are expected to choose “improve machines” from a set of alternatives including commonly chosen distracters. EiE students were 12% more likely to choose the correct answer on the post-assessment ($p<.001$). Students in grade 4 and in grade 5 both improved significantly on this item ($p<.01$).

Question 6:

Jamal is a mechanical engineer. For his job, Jamal might:

A. install wiring in houses.

B. repair bicycles.

C. predict the weather.

D. improve machines.

Table 29. **Windmills Unit: More Engineering Questions**		**N=**	**Pre**	**Post**	**McNemar p=**
2. (MCAS) Ruben is trying to figure out which way the wind is blowing. Which of the following would be **best** for him to observe to help him find the direction of the wind? [a flag on a pole]	Total (Grade 2)	90	67.8	82.2	**0.007**
4a. Shara is making a windmill, but cannot make it spin. She makes the blades bigger, but it still does not spin. Check ALL of the things that she might do next to improve her windmill: Add more blades [yes]	Total	374	18.2	31.0	**0.000**
	Grade 4	136	13.2	25.0	**0.002**
	Grade 5	181	18.8	36.5	**0.000**
4b. …Check ALL of the things that she might do next to improve her windmill: Put holes in the blades [no]	Total	374	67.9	76.2	**0.004**
	Grade 4	136	69.9	76.5	0.122
	Grade 5	181	69.6	76.8	0.117
4c. …Check ALL of the things that she might do next to improve her windmill: Change the material of the blades [yes]	Total	374	63.4	74.1	**0.000**
	Grade 4	136	61.8	63.2	0.845
	Grade 5	181	69.1	84.0	**0.001**
4d. …Check ALL of the things that she might do next to improve her windmill: Change the angle of blades [yes]	Total	373	68.9	84.5	**0.000**
	Grade 4	135	61.5	77.0	**0.000**
	Grade 5	181	79.0	93.9	**0.000**
5. Windmills and sailboats: [use wind energy.]	Total	358	76.5	84.1	**0.001**
	Grade 4	132	72.0	74.2	0.690
	Grade 5	175	88.0	95.4	**0.011**
6. Jamal is a mechanical engineer. For his job, Jamal might: [improve machines.]	Total	341	73.3	84.8	**0.000**
	Grade 4	129	70.5	82.9	**0.002**
	Grade 5	165	75.8	89.7	**0.001**

Gender Differences on the Designing Windmills Assessments

For the most part, male and female students did not perform significantly differently on the *Designing Windmills* assessments (Table 30). Male students, however, were statistically more likely than females to answer correctly on both the pre- and post-assessments for question 1 (about items that show how hard the wind is blowing) and question 3a (identifying a glider as using the energy of the wind). Both male and female students improved significantly on these two questions.

Table 30. Designing Windmills Unit: Tests for Gender Differences									Male / Female Differences	
	Female				Male				PRE	POST
Q#	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	489	10.6	19.4	**0.000**	467	18.2	28.3	**0.000**	**0.001**	**0.001**
3a	543	63.2	71.1	**0.002**	528	71.4	82.2	**0.000**	**0.004**	**0.000**
3b	543	87.5	90.8	0.069	529	85.6	87.9	0.276	0.351	0.159
3c	542	86.5	92.1	**0.002**	529	85.6	93.2	**0.000**	0.699	0.474
3d	351	13.7	12.0	0.519	352	11.4	9.9	0.615	0.419	0.376
3e	543	96.5	95.4	0.405	530	97.0	96.8	1.000	0.646	0.236
3f	543	91.9	94.1	0.155	530	90.8	94.3	**0.029**	0.461	0.864
4a	192	20.3	33.9	**0.001**	177	16.4	28.8	**0.005**	0.353	0.314
4b	192	68.8	75.5	0.111	177	67.8	76.8	**0.033**	0.960	0.701
4c	192	60.9	76.6	**0.000**	177	66.1	71.2	0.243	0.282	0.228
4d	191	70.2	84.8	**0.000**	177	68.4	83.6	**0.000**	0.646	0.825
5	182	75.8	81.9	0.080	171	76.6	86.0	**0.005**	0.848	0.422
6	171	75.4	85.4	**0.009**	165	70.9	84.2	**0.001**	0.391	0.616

Summary of the Designing Windmills Results

EiE students improved significantly on most of the *Designing Windmills* assessment questions. Overall, however, results for the *Designing Windmills* unit assessment with control comparison do not show that test students performed any better on these assessments than EiE control. Male and female performance on the assessment questions was roughly equivalent.

Results for the Making Work Easier Unit Assessments

The *Making Work Easier* EiE curriculum unit focuses on industrial engineering and the design of factory subsystems using simple machines. Students participating in this curriculum unit learned about processes as a form of technology. They improved an assembly line (Lesson 2), and they tested different simple machines and measured mechanical advantage (Lesson 3). For the final design challenge (Lesson 4), they designed and improved “factory subsystems” to move potatoes from one place in the classroom to another.

Students were asked to identify simple machines, processes, and technologies on the assessments. They were also asked questions about improving assembly lines, and about the application of force in different situations using different simple machines. Students improved significantly on nearly all of these questions and items—15 out of 21.

Making Work Easier Unit: Questions with Control Comparison

Twelve questions on the Making Work Easier unit assessment were completed by both the control sample and the test (EiE) sample. The text for these questions can be found in Table 31. Question 1 was drawn from the 2003 MCAS [7]; question 2 was drawn from the 2002 MCAS [8]. The first three questions were given only to Massachusetts students (both control and test).

Table 31. Making Work Easier Unit: Assessment Questions (Text)	
Question #	**Question Text**
1	(MCAS) A bicycle is considered a complex machine because it is [made up of more than one simple machine.]
2	(MCAS) … In which direction should force be applied to the crowbar in order to remove the nail from the board? [Direction 2 shows a hand pulling up, away from the nail]
3	The diagrams below represent the position of a balance with weights on it. All the weights have the same mass. Which diagram is NOT correct? [B: balanced with extra weight on the longer end]
4a	What kinds of simple machines are represented in the pictures below? Draw lines from the name of each simple machine to the picture that shows an example of it in use: Inclined plane [ladder].
4b	Lever matches: [pliers]
4c	Pulley matches: [blinds]
4d	Screw matches: [drill]
4e	Wedge matches: [axe]
4f	Wheel matches: [tricycle]
5	The picture shows a rope and pulley being used to lift weight. Which arrow shows the direction in which the force is applied to the rope and pulley? [C: down]
6	Which of the following is a technology? [all of the above]
7	Which technology would NOT decrease the force needed to move the box? [a (single) pulley]

The analysis for the first 3 questions, given only to Massachusetts students, is given in Table 32. The test sample consisted of grade 3 (N=18), grade 4 (N=30), and grade 5 students (N=14). The control sample consisted only of grade 4 (N=74) and grade 5 students (N=131); it is therefore more heavily weighted toward older students.

On question 1, both groups improved significantly (p<.001). The test sample did significantly better than control on the post-assessment (p<.05). On question 2 the test sample did significantly worse on the pre-assessment (p<.05) but by the post-assessment results were statistically the same. The EiE (test) students improved significantly on question 2 (p<.01), but control did not. Neither group performed significantly better on the pre- vs. the post-assessment for question 3.

Table 32. Making Work Easier Unit: Assessment Questions with Control comparison (MA only)										**Test / Control Differences**	
		MA EiE Test				**MA Control**				**PRE**	**POST**
Q#	**Group**	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
1	Total	62	41.9%	79.0%	**0.000**	203	43.3%	65.5%	**0.000**	0.814	**0.025**
2	Total	62	40.3%	64.5%	**0.001**	205	57.6%	64.9%	0.137	**0.017**	0.733
3	Total	60	46.7%	60.0%	0.134	198	51.0%	50.5%	1.000	0.444	0.187

Question 4 (items a through f) asked students to identify simple machines from pictures such as pliers, a ladder, and so on. This question was given to a national sample of students (Table 33) in grades 2, 3, 4, and 5 as well as to MA control students in grades 4 and 5. The grade 3 test sample was too small to report (N=47), as was the grade 4 EiE control sample (N=49). One important consideration is that simple machines are heavily taught in the control population in preparation for the MCAS (the Massachusetts state assessments). In the realm of identifying simple machines, EiE appears to be doing at least as well as the current curriculum used by the control population. Both test and control improved significantly on questions 4a, 4b, 4c, and 4e (p<.001). All grade subgroups improved significantly on these four questions, with one exception: grade 2 did not improve significantly on question 4b.On questions 4a-4c, there were no significant differences between test and control on either the pre-assessment or the post-assessment. The control group performed significantly better on question 4e (p<.05) on the pre-assessment. On questions 4d (screw=drill) and 4f (wheel=tricycle), only test students improved significantly (p<.001). Control students did significantly better on the pre-assessment for both of these questions; however test students did significantly better on the post-assessment for question 4f (p<.01), both overall and in grades 4 and 5.

Table 33. Making Work Easier Unit: Assessment Questions										**Test / Control Differences**	
		EiE Test				**MA Control**				**PRE**	**POST**
Q#	**Group**	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
4a	Total	378	46.8%	78.3%	**0.000**	122	46.7%	74.6%	**0.000**	0.990	0.402
	Grade 2	50	30.0%	66.0%	**0.001**						
	Grade 4	87	52.9%	88.5%	**0.000**	46					
	Grade 5	198	53.5%	81.8%	**0.000**	76	44.7%	77.6%	**0.000**	0.204	0.532
4b	Total	401	32.4%	59.4%	**0.000**	128	28.1%	55.5%	**0.000**	0.369	0.450
	Grade 2	53	28.3%	39.6%	0.307						
	Grade 4	91	26.4%	67.0%	**0.000**	47					
	Grade 5	212	40.1%	67.0%	**0.000**	81	25.9%	55.6%	**0.000**	**0.020**	0.092
4c	Total	402	65.4%	88.8%	**0.000**	130	56.2%	83.1%	**0.000**	0.095	0.125
	Grade 2	51	37.3%	76.5%	**0.000**						
	Grade 4	93	64.5%	91.4%	**0.000**	49					
	Grade 5	215	77.7%	94.0%	**0.000**	81	53.1%	84.0%	**0.000**	**0.000**	**0.020**
4d	Total	410	77.3%	86.6%	**0.000**	130	86.2%	92.3%	0.096	**0.042**	0.083
	Grade 2	54	72.2%	88.9%	**0.049**						
	Grade 4	93	76.3%	84.9%	0.115	49					
	Grade 5	216	81.9%	91.2%	**0.001**	81	86.4%	91.4%	0.388	0.503	0.946
4e	Total	390	39.0%	69.5%	**0.000**	126	50.8%	73.0%	**0.000**	**0.014**	0.488
	Grade 2	51	11.8%	45.1%	**0.000**						
	Grade 4	88	30.7%	69.3%	**0.000**	47					
	Grade 5	211	52.6%	79.1%	**0.000**	79	51.9%	81.0%	**0.000**	0.983	0.599
4f	Total	407	70.5%	90.9%	**0.000**	129	82.2%	81.4%	1.000	**0.009**	**0.008**
	Grade 2	53	50.9%	77.4%	**0.016**						
	Grade 4	92	68.5%	94.6%	**0.000**	47					
	Grade 5	216	79.2%	97.2%	**0.000**	82	80.5%	84.1%	0.678	0.815	**0.000**
5	Total	565	63.4%	76.8%	**0.000**	201	68.2%	75.1%	0.098	0.156	0.772
	Grade 4	104	70.2%	76.9%	0.311	52	57.7%	67.3%	0.424	0.132	0.120
	Grade 5	373	67.3%	85.3%	**0.000**	70	77.1%	87.1%	0.143	0.089	0.562
6	Total	577	28.1%	56.5%	**0.000**	195	35.4%	52.3%	**0.000**	0.130	0.078
	Grade 4	103	27.2%	44.7%	**0.008**	54	31.5%	48.1%	0.136	0.547	0.274
	Grade 5	381	29.7%	64.8%	**0.000**	71	57.7%	66.2%	0.210	**0.000**	0.818
7	Total	582	23.2%	30.6%	**0.003**	201	16.9%	15.4%	0.775	0.082	**0.000**
	Grade 4	103	25.2%	30.1%	0.500	55	14.5%	20.0%	0.581	0.126	0.242
	Grade 5	384	22.1%	33.9%	**0.000**	69	20.3%	18.8%	1.000	0.859	**0.009**

Questions 5, 6, and 7 were administered nationally to both an EiE test sample and an EiE control sample (who completed another EiE unit but not the *Making Work Easier* unit). Test students in grades 2-5 completed the assessment; results for grade 2 (N=48) and grade 3 (N=47) were not analyzed due to insufficient sample size. Control students in grades 2 through 6 completed the assessment; results for grade 3 (N=62) and grade 6 (N=17) are not reported because of a lack of matching test samples.

Question 5 asked about the force applied to a pulley. EiE (test) students improved significantly on this item ($p<.001$) while control did not; however there were no significant differences between the two samples on either the pre- or the post-assessment. Only grade 5 test students improved significantly ($p<.001$).

Question 6 asked students to identify technologies from a list. Two of the examples were processes; one was “a computer”, which students typically think of as technology. Students were much more likely ($p=.000$) to answer this question correctly (“D. all of the above”) after completing the unit than before, though barely more than half still answered it correctly. This is one of the key learning objectives of the *Making Work Easier* unit: that processes designed by people are technologies. Both test and control students improved significantly on this question ($N<.001$). This is not surprising—in fact it is encouraging—because it appears to indicate that students completing EiE units other than *Making Work Easier* also learned that processes can be technologies.

Question 6:

2. Which of the following is a technology?

A. a way to make air clean

B. a computer

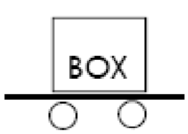
C. a method for putting together wheelchairs

D. all of the above

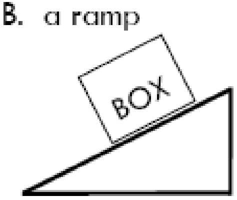
Question 7:

Which technology would NOT decrease the force needed to move the box?

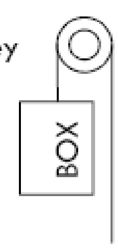
A. a cart



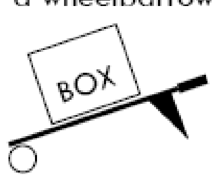
B. a ramp



C. a pulley



D. a wheelbarrow



Question 7 asked students to identify which simple machine does not reduce the force applied (a single pulley). Test students improved significantly (p<.01) while control students did not; test students also did significantly better on the post-assessment (p<.001) than control students. This question was especially difficult for students, however, with fewer than a third answering correctly even on the post-assessment. This may indicate a need for more careful attention to the kinds of mechanical advantage afforded by each simple machine, which is a sub-focus of Lesson 3.

Making Work Easier Unit: Questions without Control Comparison

Table 34 displays the results for analysis of nine questions which were administered to a Massachusetts test sample only. This sample included grades 3 through 5; grade 3 (N=8) is not reported separately because of insufficient sample size.

Table 34. Making Work Easier Unit: Engineering Questions		**N**	**Pre**	**Post**	**McNemar p=**
8a. To improve an assembly line, an industrial engineer might: make each person do many steps of the process [False]	Total	287	52.6%	67.2%	**0.000**
	Grade 4	50	58.0%	50.0%	0.523
	Grade 5	229	52.0%	72.1%	**0.000**
8b. To improve an assembly line, an industrial engineer might: put the tables where the workers can easily reach [True]	Total	287	58.9%	79.4%	**0.000**
	Grade 4	50	46.0%	68.0%	0.052
	Grade 5	229	61.6%	83.8%	**0.000**
8c. To improve an assembly line, an industrial engineer might: decide what color the boxes should be [False]	Total	287	88.9%	88.9%	1.000
	Grade 4	50	90.0%	82.0%	0.289
	Grade 5	229	89.1%	90.8%	0.597
8d. To improve an assembly line, an industrial engineer might: change the order to make the process go faster [True]	Total	287	75.6%	81.5%	0.071
	Grade 4	50	80.0%	82.0%	1.000
	Grade 5	229	75.5%	83.0%	0.053
9. The force required to lift the book will now be:	Total	285	43.2%	58.2%	**0.000**
	Grade 4	50	60.0%	74.0%	0.143
	Grade 5	227	40.5%	56.8%	**0.001**
10a. Assembling a backpack is a process	Total	286	67.8%	86.7%	**0.000**
	Grade 4	50	62.0%	76.0%	0.230
	Grade 5	228	69.3%	89.9%	**0.000**
10b. A backpack is a process	Total	286	86.0%	85.7%	1.000
	Grade 4	50	96.0%	76.0%	**0.006**
	Grade 5	228	84.2%	89.0%	0.144
10c. A double pulley is a process	Total	286	38.8%	59.1%	**0.000**
	Grade 4	50	34.0%	40.0%	0.648
	Grade 5	228	40.4%	63.6%	**0.000**
10d. Baking cookies is a process	Total	286	44.8%	65.4%	**0.000**
	Grade 4	50	40.0%	48.0%	0.388
	Grade 5	228	46.1%	71.1%	**0.000**

Items 8a through 8d were the parts of a "choose all that apply" question asking about how to improve an assembly line—a direct assessment of lesson 2 of the unit, when students improved their own assembly lines. Students improved significantly (p<.001) on two of the items; on the others they got 76-89% correct both pre- and post-. However, the answers for 8a and 8c could be argued as either true or false; this question has therefore been changed for newer versions of this assessment.

Question 9 asked students how changing a lever so less work is required will affect the amount of force that needs to be applied to lift some books. Students improved significantly (p<.001) on this question as well. Measuring forces and determining their direction was the focus of Lesson 3 of the *Marvelous Machines* unit. Students improved significantly on this and on the other two questions about forces as well (5 and 7).

Question 10, asking students to identify processes, included "choose all that apply" items 10a-10d. Students improved significantly (p<.001) on all but the easiest of these, "a backpack", which about 86% of all students answered correctly on both the pre- and post-assessments.

Gender Differences on the Making Work Easier Assessments

There were a number of gender differences on the *Making Work Easier* assessments. Males were more likely than females to correctly answer questions 2, 3, 4e, 8a, 8d, and 9 on the pre-assessment. Males were also more likely than females to correctly answer questions 2, 3, 4b, 5, and 8c on the post-assessment. Males improved significantly (p<.01) from pre- to post- on question 7 while females did not; females improved significantly from pre- to post- on question 2 (p<.05), question 8a (p<.001), question 8d (p<.05), and question 9 (p<.01) while males did not. Females made greater gains on the assessments, but overall males did better on both the pre-assessments and the post-assessments.

Table 35. Making Work Easier Unit: Tests for Gender Differences									**Male / Female Differences**	
	Female				**Male**				**PRE**	**POST**
Q#	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
1	134	44.8%	67.2%	**0.000**	131	41.2%	70.2%	**0.000**	0.609	0.510
2	134	44.8%	56.7%	**0.044**	133	62.4%	72.9%	0.076	**0.004**	**0.005**
3	129	38.8%	38.8%	1.000	129	61.2%	66.7%	0.337	**0.000**	**0.000**
4a	170	45.9%	76.5%	**0.000**	184	49.5%	80.4%	**0.000**	0.643	0.538
4b	178	28.7%	53.9%	**0.000**	198	36.4%	64.6%	**0.000**	0.099	**0.018**
4c	178	65.2%	87.6%	**0.000**	199	63.8%	90.5%	**0.000**	0.757	0.534
4d	184	73.9%	83.7%	**0.010**	201	78.6%	88.6%	**0.002**	0.233	0.169
4e	172	33.7%	65.1%	**0.000**	194	44.8%	73.2%	**0.000**	**0.047**	0.067
4f	182	67.6%	90.7%	**0.000**	201	72.6%	91.5%	**0.000**	0.351	0.620
5	269	62.1%	72.9%	**0.002**	270	66.3%	81.9%	**0.000**	0.277	**0.007**
6	278	25.5%	57.9%	**0.000**	274	29.9%	54.0%	**0.000**	0.261	0.384
7	282	22.3%	28.7%	0.095	275	23.3%	33.8%	**0.003**	0.957	0.186
8a	151	46.4%	67.5%	**0.000**	134	60.4%	66.4%	0.366	**0.015**	0.843
8b	151	57.6%	80.1%	**0.000**	134	60.4%	78.4%	**0.004**	0.677	0.787
8c	151	90.1%	84.1%	0.108	134	88.1%	94.0%	0.077	0.572	**0.013**
8d	151	68.2%	79.5%	**0.021**	134	83.6%	83.6%	1.000	**0.002**	0.515
9	148	36.5%	55.4%	**0.002**	135	50.4%	61.5%	0.063	**0.015**	0.303
10a	149	64.4%	86.6%	**0.000**	135	71.1%	86.7%	**0.001**	0.312	0.991
10b	149	85.9%	87.2%	0.868	135	85.9%	83.7%	0.701	0.990	0.316
10c	149	35.6%	58.4%	**0.000**	135	42.2%	59.3%	**0.004**	0.285	0.929
10d	149	47.7%	67.8%	**0.000**	135	41.5%	62.2%	**0.000**	0.273	0.272

Summary of the Making Work Easier Results

EiE students improved significantly on most of the assessment questions for the *Making Work Easier* unit. They improved somewhat but not dramatically more than a control comparison group. Males performed better than females on both the pre-assessments and the post-assessments, but females made greater gains on the assessments.

Results for the Designing Hand Pollinators Unit Assessments

The *Designing Hand Pollinators* unit is focused primarily on agricultural engineering, natural and technological systems, and connections to pollinating and pest insects, though there are also strong connections to plant science. In lesson 2, students learn about Integrated Pest Management as an example of a method for managing the food web natural system of predator insects, pest insects, and human agriculture instead of simply eradicating pest insects with pesticides, since that has the potential to cause problems with whole ecosystems. In lesson 3, students test different materials for their ability to pick up pollen, learning that materials with a large surface area can pick up more pollen. In lesson 4, students design hand pollinator models for different (modeled) shapes of flowers.

Hand Pollinators Unit: Questions with Control Comparison

Both test and control sample responses were collected for nine questions (see Table 36 for question text). The first three of these are all drawn from the MCAS; responses were collected only in Massachusetts and only from grade 2 students (Table 37). Responses to the other six questions were collected nationally from EiE test students in grades 2 through 5 and EiE control students in grades 3 through 5 (Table 38). Control responses from grade 3 are not shown in Table 38 because of the small subsample size (N=25). The national test sample is more heavily weighted toward younger students, while the control sample is more heavily weighted toward older students.

Table 36. Designing Hand Pollinators Unit: Assessment Questions (Text)

Question #	Question Text
1	(MCAS) Which is the correct order of the metamorphosis of a butterfly? [egg, larva, pupa, adult]
2	(MCAS) You wish to closely observe a small insect. Which tool is the best to use? [a magnifying glass]
4	Paper wasps eat caterpillars. Caterpillars eat tomato plants. If Mario kills the paper wasps in his garden, what will probably happen? [There will be more caterpillars eating his tomato plants.]
5a	Which of the following do most plants need to grow and make seeds? (sunlight) [True]
5b	Which of the following do most plants need to grow and make seeds? (insects) [True]
5c	Which of the following do most plants need to grow and make seeds? (people) [False]
5d	Which of the following do most plants need to grow and make seeds? (water) [True]
6	Ari sees insects flying around his favorite pumpkin plants. He is worried they might hurt his plants. What do you think he should do first to make sure the insects won't hurt his plants? [Observe the insects to learn what they are doing.]

Question 1 asked about the life cycle of a butterfly [6], science which is related to this unit. Both test and control students improved significantly on this question (p<.001); however MA EiE test students were significantly (p<.05) more likely to answer correctly on the post-assessment than control students. Neither test nor control students improved significantly on question 2 about which tool to use to observe a small insect [9]; this question was much easier for students—more than 80% answered correctly on both the pre- and post-assessments. Question 3 was about observing another small creature: a worm, not an insect; this was a simplified version of an MCAS question [10]. MA EiE test students improved significantly on this question (p<.001) while control students did not, and they performed significantly better than control on the post-assessment (p<.01).

Table 37. Designing Hand Pollinators Unit: Assessment Questions with Control Comparison (MA, grade 2 only)										Test / Control Differences	
		MA EiE Test				MA EiE Control				PRE	POST
Q#	Group	N	Pre	Post	McNemar p=	N	Pre	Post	McNemar p=	Phi p=	Phi p=
1	Total	113	53.1	94.7	**0.000**	65	40.0%	86.2%	**0.000**	0.082	**0.046**
2	Total	113	86.7	92.9	0.581	64	82.8	87.5	0.189	0.340	0.307
3	Total	110	46.4	67.3	**0.000**	65	36.9	43.1	0.481	0.238	**0.002**

Results from questions 4 through 6 are more mixed, and show evidence that the samples themselves are significantly different; however test students were still more likely to improve significantly than control students (Table 38). Question 4 asked students to make a prediction about what would happen if predatory wasps were removed from a food web system. This question is related in content to Lesson 2, with its theme of pest management, but it also asks students to extrapolate about the effects of interference in a natural system. EiE test students improved significantly on this question both overall (p<.001) and at all grades. Overall control students were significantly more likely to answer correctly on the pre-assessment (p<.01)—not surprising since the control sample has a much higher proportion of grade 4 and 5 students. Grade 5 students were significantly more likely to correctly answer on the post-assessment (p<.05).

Question 5 was a choose-all-that-apply question with four parts. Students were asked to choose the items needed by a plant to grow and make seeds. EiE test students improved significantly on items 5a (sunlight) and 5b (insects); control students improved significantly on item 5b only. Items 5c and 5d showed a ceiling effect (all responses >80%), though test students performed significantly better both pre- and post- on item 5d. Control students did significantly better on the pre-assessment for item 5a, but test students did significantly better on both pre- and post for items 5b and 5d.

Question 6:

Ari sees insects flying around his favorite pumpkin plants. He is worried they might hurt his plants. What do you think he should do first to make sure the insects won't hurt his plants? Circle **ONE** answer.

A. Cover the pumpkin plants with a box.

B. Observe the insects to learn what they are doing.

C. Kill the insects.

D. Water the plants.

Both control and test students improved significantly on question 6 (p<.001), which focused on an attitude promoted in the story and the unit: that scientists and engineers should try to understand a natural system before they make significant changes to it. This was a theme of both the storybook (Lesson 1) and of Lesson 2, and given the curriculum content, students should have answered "B. Observe the insects to learn what they are doing". Control students did significantly better on the pre-assessment (p<.001), but there were no significant differences between the post-assessments. All grade subgroups improved significantly both test (p<.001) and control (p<.01); however the only significant differences between rates of correct answers were at grade 5: control students did significantly better on the pre-assessments (p<.05), while test students did significantly (p<.001) and dramatically (33%) better on the post-assessment.

Table 38. Designing Hand Pollinators Unit: Assessment Questions with Control Comparison

		EiE Test				EiE Control				Test / Control Differences PRE	Test / Control Differences POST
Q#	**Group**	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
4	Total	497	68.6	80.9	**0.000**	298	79.5	82.6	0.306	**0.001**	0.547
	Grade 2	168	61.9	73.2	**0.014**						
	Grade 3	171	67.3	78.9	**0.006**						
	Grade 4	92	78.3	90.2	**0.027**	115	85.2	88.7	0.503	0.175	0.724
	Grade 5	66	75.8	92.4	**0.007**	158	76.6	78.5	0.736	0.895	**0.012**
5a	Total	326	81.3	90.5	**0.000**	292	90.8	87.7	0.222	**0.002**	0.260
	Grade 2	55	87.3	87.3	1.000						
	Grade 3	136	74.3	89.7	**0.001**						
	Grade 4	69	94.2	94.2	1.000	117	96.6	86.3	**0.008**†	0.476	0.094
	Grade 5	66	77.3	90.9	**0.035**	158	85.4	88.6	0.405	0.137	0.612
5b	Total	326	23.3	57.1	**0.000**	292	15.4	31.8	**0.000**	**0.021**	**0.000**
	Grade 2	55	41.8	78.2	**0.000**						
	Grade 3	136	21.3	61.0	**0.000**						
	Grade 4	69	23.2	33.3	0.189	117	19.7	48.7	**0.000**	0.859	**0.041**
	Grade 5	66	12.1	56.1	**0.000**	158	13.3	19.6	0.132	0.812	**0.000**
5c	Total	326	86.5	87.7	0.699	292	91.4	89.7	0.526	0.063	0.434
	Grade 2	55	81.8	83.6	1.000						
	Grade 3	136	86.8	84.6	0.711						
	Grade 4	69	91.3	89.9	1.000	117	89.7	88.0	0.832	0.703	0.705
	Grade 5	66	84.8	95.5	0.065	158	91.8	89.9	0.607	0.120	0.172
5d	Total	326	93.6	95.7	0.265	292	88.0	88.4	1.000	**0.008**	**0.001**
	Grade 2	55	89.1	94.5	0.453						
	Grade 3	136	94.9	95.6	1.000						
	Grade 4	69	97.1	94.2	0.687	117	91.5	86.3	0.263	**0.049**	0.094
	Grade 5	66	90.9	98.5	0.063	158	85.4	90.5	0.152	0.267	**0.035**
6	Total	492	45.5	72.0	**0.000**	298	58.7	71.5	**0.000**	**0.000**	0.880
	Grade 2	164	46.3	66.5	**0.000**						
	Grade 3	171	40.4	63.2	**0.000**						
	Grade 4	92	55.4	83.7	**0.000**	115	59.1	76.5	**0.003**	0.523	0.202
	Grade 5	65	43.1	92.3	**0.000**	158	59.5	70.3	**0.009**	**0.019**	**0.000**

† Significant regression (p<.01)

Hand Pollinators Unit: Questions without Control Comparison

Table 39 shows the analysis for thirteen questions which were given only to EiE test students. Grades 2, 3, and 5 completed these assessment questions; grade 3 is not reported as a subgroup because of the small sample size (N=37). Eight of these questions (7a through 9; 12a-12d) focus on the engineering content of the unit; EiE students improved significantly overall on all of these questions but one (12c), on which grade 5 did improve significantly ($p<.05$). Three questions focused on the science of pollination, which is the science content most relevant to the unit; students improved significantly on all of these three questions both overall and at all grade levels ($p<.001$).

For question 7, students were asked to consider four different things (question items 7a-7d) and mark all those that they would consider in designing a hand pollinator. On the post-assessment, they were significantly more likely (13%-34% improvement) to say that they should consider the shape of the flower (7a: $p<.01$), whether the pollinator material can pick up pollen (7c: $p<.001$), and whether the material can drop off pollen (7d: $p<.001$). They were significantly less likely (30%) to say that they should consider the color of the flower (7b: $p<.001$). In lesson 4, students designed their own hand pollinators; this experience clearly affected their ability to answer these questions.

When asked about how they should pollinate flowers in their garden if the pollinating insect is not available (question 8), 93% of students answered on the post-assessment that they would use a hand pollinator (a 39% increase). Using a hand pollinator for pollination of personal plant was the central premise of the storybook (Lesson 1) and the distractor “A. Introduce a new kind of insect” was discussed as an issue in the story. The improvement was significant overall ($p<.001$) and at both grades ($p<.001$).

Question 8:

Lerone notices that the insects that used to pollinate her favorite flower don’t live in her garden any more. What is the **best** way for her to pollinate her flowers?

A. Introduce a new kind of insect to pollinate the flower.

B. Spray pesticides.

C. Plant more of the flower.

D. Pollinate the flower by hand.

Question 9 and questions 12a-12d asked about things that agricultural engineers might do for their jobs. Students showed significant improvement ($p<.001$; 22-39% increase) on all of these questions except that grade 2 students did not extend their concept of agricultural engineering to “figure out the best way to water fields” (12c), a role of agricultural engineers which was not directly discussed in the unit. Grade 2 students were significantly less likely to answer this question correctly ($p<.05$), while grade 5 students were significantly more likely to answer correctly ($p<.05$). This suggests that teachers might want to focus more on the generic definition of agricultural engineering—“engineers who design and improve technologies for agriculture”—when discussing specific examples of what agricultural engineers do.

Questions 10, 11, and 13 asked students about the pollination system. Question 13 has since been redesigned to reduce confusion, removing bees from the question, since bees actually collect pollen as well as nectar for their own purposes. Question 13 was asked only of grade 2 and grade 3 students.

Table 39. Designing Hand Pollinators Unit: Assessment Questions		**N**	**Pre**	**Post**	**McNemar p=**
7a. Melissa should consider (shape of flower) when designing a hand pollinator.	Total	235	46.4	61.7	**0.001**
	Grade 2	103	49.5	68.9	**0.008**
	Grade 5	95	47.4	57.9	0.154
7b. Melissa should consider (color of flower) when designing a hand pollinator.	Total	235	65.1	94.5	**0.000**
	Grade 2	103	60.2	93.2	**0.000**
	Grade 5	95	65.3	97.9	**0.000**
7c. Melissa should consider (if material can pick up pollen) when designing a hand pollinator.	Total	235	78.7	91.5	**0.000**
	Grade 2	103	82.5	90.3	0.115
	Grade 5	95	76.8	95.8	**0.000**
7d. Melissa should consider (if material can drop off pollen) when designing a hand pollinator.	Total	235	56.6	91.1	**0.000**
	Grade 2	103	66.0	93.2	**0.000**
	Grade 5	95	49.5	91.6	**0.000**
8. What is the best way for Lerone to pollinate her flowers?	Total	223	54.7	93.3	**0.000**
	Grade 2	94	64.9	93.6	**0.000**
	Grade 5	94	47.9	91.5	**0.000**
9. If you are an agricultural engineer, your job could involve:	Total	224	17.0	44.6	**0.000**
	Grade 2	95	21.1	69.5	**0.000**
	Grade 5	95	12.6	22.1	0.136
10. Insects are useful to plants because they:	Total	225	57.8	85.8	**0.000**
	Grade 2	98	64.3	85.7	**0.001**
	Grade 5	91	56.0	85.7	**0.000**
11. Which part of this plant is NOT part of the pollination system?	Total	228	46.5	71.5	**0.000**
	Grade 2	102	52.0	67.6	**0.023**
	Grade 5	89	44.9	78.7	**0.000**
12a. Check ALL of the things that agricultural engineers do for their work. (Keep insects from eating crops)	Total	245	52.2	73.5	**0.000**
	Grade 2	117	63.2	82.9	**0.001**
	Grade 5	91	44.0	62.6	**0.030**
12b. Check ALL of the things that agricultural engineers do for their work.(Pollinate plants we use for food)	Total	245	33.1	60.4	**0.000**
	Grade 2	117	45.3	65.8	**0.006**
	Grade 5	91	25.3	57.1	**0.000**
12c. Check ALL of the things that agricultural engineers do for their work.(Figure out the best way to water fields)	Total	245	47.3	46.9	1.000
	Grade 2	117	56.4	39.3	**0.019**†
	Grade 5	43	52.7	65.1	**0.019**
12d. Check ALL of the things that agricultural engineers do for their work.(Drive a tractor that harvests food)	Total	244	39.8	78.3	**0.000**
	Grade 2	116	41.4	82.8	**0.000**
	Grade 5	91	40.7	72.5	**0.000**
13. Why do insects like bees and butterflies visit flowers?	Total	130	42.3	66.9	**0.000**
	Grade 2	94	41.5	69.1	**0.000**

† Significant regression (p<.05)

Question 10 and 11:

Insects are useful to plants because they

A. take the nectar away from the flower.

B. take seeds away.

C. give food to the plant.

D. move pollen from one flower to another.

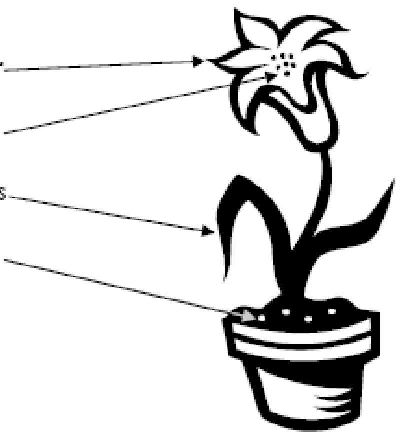
Which part of this plant is **NOT** part of the pollination system?

A. Flower

B. Pollen

C. Leaves

D. Seeds



Question 13:

Why do insects like bees and butterflies visit flowers? Circle the **BEST** answer.

A. to get pollen

B. to get nectar

C. because flowers are pretty

D. to find a place to live

Between 24% and 28% more students answered each of these questions correctly on the post-assessment than on the pre-assessment, changes which are highly significant ($p<.001$). All grade subgroups improved significantly. This is not surprising, as the unit as a whole focuses on the role of insects in the pollination process as the background of the design challenge (to design a hand pollinator to supplement or take the place of insect pollination on a small scale).

Gender Differences on the Designing Hand Pollinators Assessments

Male and female performances on the *Designing Hand Pollinators* assessments were roughly equivalent with only a few exceptions. Male students were significantly ($p<.01$) more likely to correctly answer question 9, about the work of agricultural engineers, on the pre-assessment. Females improved significantly ($p<.05$) on question 5a (about plants' need for sunlight) while males did not; males improved significantly ($p<.01$) on question 7a (about whether the shape of a flower matters when designing a hand pollinator) while females did not. Both males and females improved significantly on all other questions except 5c and 5d (plants' needs for people and water), which were particularly easy for students.

Table 40. Designing Hand Pollinators Unit: Tests for Gender Differences									**Male / Female Differences**	
	Female				**Male**				**PRE**	**POST**
Q#	**N**	**Pre**	**Post**	**McNemar p=**	**N**	**Pre**	**Post**	**McNemar p=**	**Phi p=**	**Phi p=**
4	226	67.3	82.3	**0.000**	227	70.9	78.9	**0.027**	0.398	0.421
5a	141	83.0	91.5	**0.017**	151	82.1	89.4	0.099	0.740	0.545
5b	141	20.4	55.3	**0.000**	151	27.0	52.1	**0.000**	0.169	0.570
5c	141	85.1	87.2	0.690	151	85.4	88.7	0.458	0.679	0.692
5d	141	93.6	97.2	0.227	151	94.7	94.7	1.000	0.691	0.290
6	224	50.0	71.4	**0.000**	225	42.2	74.7	**0.000**	0.123	0.413
7a	122	47.5	59.0	0.098	111	45.9	64.9	**0.004**	0.711	0.434
7b	122	63.1	95.9	**0.000**	111	66.7	92.8	**0.000**	0.506	0.204
7c	122	77.9	91.0	**0.004**	111	79.3	91.9	**0.009**	0.739	0.985
7d	122	52.5	91.0	**0.000**	111	60.4	91.0	**0.000**	0.234	0.829
8	118	47.5	92.4	**0.000**	103	64.1	94.2	**0.000**	**0.008**	0.787
9	118	16.9	40.7	**0.000**	104	17.3	49.0	**0.000**	0.977	0.363
10	118	58.5	83.9	**0.000**	105	56.2	87.6	**0.000**	0.767	0.650
11	117	45.3	74.4	**0.000**	109	47.7	68.8	**0.001**	0.780	0.240
12a	125	48.8	73.6	**0.000**	118	55.9	74.6	**0.007**	0.292	0.952
12b	125	37.6	56.8	**0.003**	118	28.8	63.6	**0.000**	0.117	0.265
12c	125	47.2	47.2	1.000	118	47.5	47.5	1.000	0.975	0.810
12d	125	40.8	79.2	**0.000**	117	38.5	76.9	**0.000**	0.729	0.612
13	68	48.5	69.1	**0.034**	60	36.7	66.7	**0.001**	0.127	0.789

Summary of the Designing Hand Pollinators Results

EiE students improved significantly on nearly all questions. Where comparison to control was available, test students tended to do at least slightly better (and sometimes much better) than control, though the comparison is muddy because of sample differences: the control sample is much more heavily weighted towards older students. Differences between girls and boys were minor or nonexistent on these assessments.

Conclusion

Engineering is Elementary students consistently showed improvement—frequently dramatic improvement—on post-assessments designed to assess student understanding of science and engineering concepts. Where comparison to a control sample is available, EiE students have, for the most part, performed significantly better than the control students. These results show that EiE students:

- Demonstrate a much clearer understanding of technology as human-made. They are much more likely on the post-assessment than on the pre-assessment to choose all human-made items as technology, even those which are not "cutting-edge" and do not use electricity. They are also more likely to correctly identify technologies than the control sample.
- Demonstrate a much clearer understanding of the work of engineers as involving design and teamwork. On the post-assessments, they are much more likely than control students—and more

likely than on their own pre-assessments—to choose such non-canonical jobs as “develop better bubble gum” and “design ways to clean water” as the work of engineers, and much less likely to choose technical or construction non-engineering jobs such as “install wiring” and “repair cars”.
- Demonstrate a better grasp of relevant vocabulary, including the words “engineer”, “design”, and “technology”.
- Demonstrate a clearer understanding on the post-assessment of the steps of the engineering design process and what those steps look like in short scenarios.
- Demonstrate a clearer understanding of materials, their properties, and their uses in different engineering design scenarios after completing the *Designing Water Filters,* the *Designing Walls* or the *Designing Bridges* 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 *Designing Water Filters,* the *Designing Windmills,* or the *Designing Hand Pollinators* unit.
- Are much more likely to correctly answer science content questions relating to the unit after completing the *Designing Water Filters,* the *Designing Bridges,* or the *Making Work Easier* unit.
- Demonstrate a much clearer understanding of how to improve the technologies featured in the unit after completing the *Designing Windmills* or the *Making Work Easier* unit.
- Are much more likely to correctly identify relevant aspects and types of technologies featured in the unit after completing the *Designing Bridges,* the *Designing Windmills,* or the *Making Work Easier* unit.
- Demonstrate a much clearer understanding of what a process is and how it is a type of technology after completing the *Making Work Easier* unit.
- Demonstrate a clearer understanding of the criteria for judging the effectiveness of a hand pollinator design after completing the *Designing Hand Pollinators* unit.

EiE students demonstrated on the post-assessment for the *Designing Water Filters* unit, for example, that they learned a great deal about water, water filters, the materials used in water filtration, and the work done by environmental engineers over the course of this unit. They demonstrated on the *Designing Hand Pollinators* unit post-assessment that they learned a great deal about pollination, the roles of flowers and insects in the pollination process, important characteristics of a successful hand pollinator design, and the jobs of agricultural engineers. Though it can be argued that learning about the properties of specific materials for water filtration and specific characteristics of hand pollinators are not an essential part of a child’s education, we espouse the view that it is through these specifics—which involve fun, educational activities—that students learn the more broad, basic lessons about engineering, technology, and engineering design. From the General Engineering assessments discussed earlier, we can see that this is true: students successfully learned what engineering and technology are, and the order and characteristics of the steps of the engineering design process.

An important goal of engineering education in the elementary grades is to introduce students to the most basic concepts of the applied sciences:
- Objects and processes in the world can be categorized as natural or as human-made.
- Human-made objects and processes can be described as technologies.
- The engineering design process is a principled process that is both different from and similar to the process of scientific discovery.
- Familiarity with materials and their properties is an important prerequisite of engineering design.
- Engineering is a profession 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.
- Engineering design can be fun, can help people, and is worth learning to do better.

- Technology and its design has enormous impact on people, societies, and the earth.

The goals of the Engineering is Elementary curriculum are to introduce students to these basic concepts, and to give them a taste of the enormous variety of technologies and designs that engineers work on. The research presented here gives strong evidence that many of these goals are being met.

Next Steps

Currently we are collecting data for new units. Our new data collection methods more closely match test and control populations. We will continue to examine more closely the effects of gender, socioeconomic status, and English proficiency on student performance. This year, we will also be collecting more control data using the updated questions, so as to enable a more complete and robust analysis, and to extend our analysis to a comparison of student learning of science topics in classrooms where EiE is integrated and those where science is taught without engineering.

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