AC 2007-9: ENGINEERING IS ELEMENTARY: CHILDREN'S CHANGING UNDERSTANDINGS OF ENGINEERING AND SCIENCE

Christine Cunningham, Museum of Science, Boston

Dr. Christine Cunningham works as the Vice President of Research at the Museum of Science, Boston. In her work, she oversees research and evaluation efforts related to engineering and science learning and teaching in the Museum and in K-12 classrooms; a curriculum development project, Engineering is Elementary: Engineering and Technology Lessons for Children; and a number of teacher professional development programs about engineering and technology for teachers of kindergarten through community college. Her projects focus on making science and engineering more accessible to marginalized populations, especially women, underrepresented minorities, and people with disabilities. She is particularly interested in the ways that the teaching and learning of engineering and science can change to include and benefit from a more diverse population. Christine received a joint BA and MA in Biology from Yale University and a PhD in Science Education from Cornell University.

Cathy Lachapelle, Museum of Science, Boston

Dr. Cathy Lachapelle currently leads the assessment efforts for the EiE curriculum, designing assessment instruments, pilot and field testing them, and conducting research on how children use the EiE materials. She has worked on a number of research and evaluation projects related to K-16 engineering education. Cathy received her S.B. in cognitive science from MIT, and her Ph.D. in Psychological Studies in Education from Stanford University.

Engineering is Elementary: Children's Changing Understandings of Science and Engineering

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. 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. 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 lessons where students investigate and test materials and processes for their designs, and culminates in a final design challenge.

A complete description of the EiE curriculum and its goals can be found in these conference proceedings, in the paper "Engineering is Elementary: An Engineering and Technology Curriculum for Children".

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 across 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. 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.

Previous research on young students' understanding of engineering and technology concepts is sparse[2-4] though research to guide the growing field of engineering education K-12 has been called for[5-6]. The current study aims, in part, to close the gap.

In this paper, we show that EiE students have learned about science and engineering from two of the ten EiE units currently available: *Designing Hand Pollinators* and *Designing Water Filters*. The performance of EiE students on post-assessments is significantly better than their performance on the pre-assessments. Where control data is available, we compare the performance of EiE students to the performance of the control students on the assessments, and show that EiE students perform significantly better than control.

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 topics and another 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, pre-assessments were administered to EiE students 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 comparable 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.

Because control data was collected in the 2005-2006 school year, comparison against a control population has not been possible for questions developed after 2005. For these more recent questions—most of them unit questions—only the EiE student results are presented.

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. Each EiE student completed a 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). Because of this, the EiE sample is larger than the control sample for all questions.

	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 were not statistically significant (Nominal by Interval Eta p=.052).

		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 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.

English Language Limited Proficiency

Of those reporting (n=1329), 7.3% of the Control students were classified as English Language Limited Proficiency (ELLP). 4.8% of EiE students reporting (n=1817) were classified as ELLP. 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%), Indian (2.0% versus 0.0%), Central/SE/East Asian (6.9% versus 4.3%) and Hispanic (13.4% versus 7.9%) students among those reporting (n=3002).

Race/ Ethnicity	White	Hispanic /Latino	Black	Asian	Native American	Multi-racial	Other	Total
Control	78.4%	7.9%	8.8%	4.3%	0.6%	0.0%	0.1%	100.0%
EiE	65.0%	13.4%	9.9%	8.9%	0.7%	1.6%	0.5%	100.0%
Total	70.1%	11.4%	9.5%	7.1%	0.6%	1.0%	0.4%	100.0%

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.

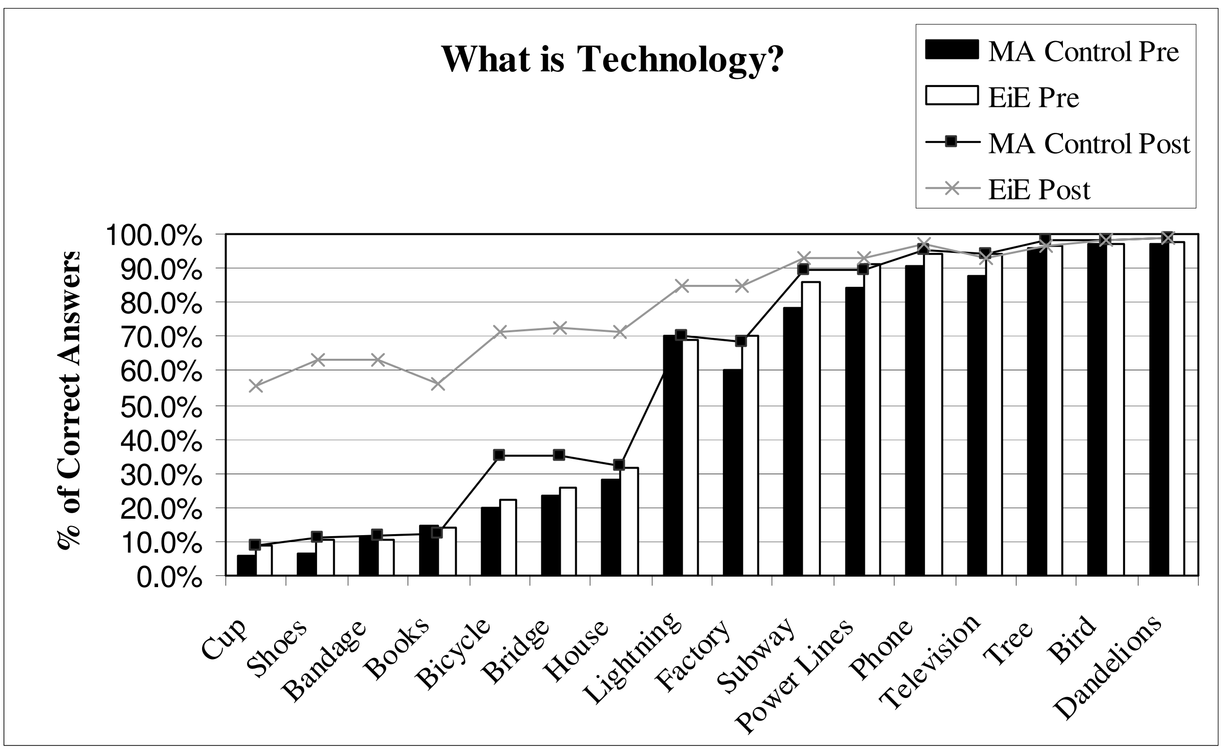
What is Technology?

For the “What is Technology?” question, students were asked to identify 12 items that were technology from 16 items presented. The chart below shows these items, ordered by the percentage answered correctly on the pre-assessments by EiE students. On the 9 more difficult items to classify—cup, shoes, bandage, books, bicycle, bridge, house, lightning, and factory—students improved dramatically (between 15% and 53%) and significantly (McNemar Test of

Symmetry p<.000) in their ability to correctly identify 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.

Students tend (correctly) not to choose the natural items as examples of technology. The exception to this rule is "lighting", which was chosen by about 30% of EiE students as an example of technology on the pre-assessment, and by about 30% of control students on both 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[1]. One possibility for why so many students chose "lightning" as an example of technology is this connection to electricity.

The same open-ended question 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.



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 shading. 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=".

On the four most difficult items to identify correctly—cup, shoes, bandage, and books—EiE students improved significantly while control students did not. EiE students also did significantly better on the post-assessments on these items than control students. The same is true of two items from the center of the table, lightning and house, which were more frequently correctly classified but still posed challenges to students. Both EiE and control students showed significant improvement on two other moderately difficult items—bicycle and bridge—but 46-49% of EiE students improved on these items, while only 13-15% of control students improved.

***What is Technology?* Questions**		**Control sample: % correct**	**EiE sample: % correct**	**Phi Coefficient p=**
Cup	Pre	5.9%	8.6%	0.001
	Post	8.6%	55.4%	0.000
	McNemar p=	0.689	0.000	
Shoes	Pre	6.4%	10.5%	0.000
	Post	10.8%	62.9%	0.000
	McNemar p=	0.169	0.000	
Bandage	Pre	10.9%	10.3%	0.899
	Post	11.5%	63.2%	0.000
	McNemar p=	0.916	0.000	
Books	Pre	14.5%	14.3%	0.765
	Post	12.5%	56.1%	0.000
	McNemar p=	0.176	0.000	
Bicycle	Pre	20.2%	22.2%	0.045
	Post	35.3%	71.1%	0.000
	McNemar p=	0.000	0.000	
Bridge	Pre	23.5%	26.0%	0.022
	Post	35.1%	72.6%	0.000
	McNemar p=	0.000	0.000	
Lightning	Pre	70.1%	68.7%	0.641
	Post	70.4%	84.5%	0.000
	McNemar p=	1.000	0.000	
House	Pre	28.3%	31.7%	0.007
	Post	32.2%	71.2%	0.000
	McNemar p=	0.397	0.000	
Factory	Pre	60.5%	70.4%	0.000
	Post	68.2%	84.9%	0.000
	McNemar p=	0.007	0.000	
Subway	Pre	78.2%	86.2%	0.000
	Post	89.7%	92.9%	0.016
	McNemar p=	0.000	0.000	
Power Lines	Pre	84.0%	91.4%	0.000
	Post	89.6%	92.8%	0.002
	McNemar p=	0.001	0.009	

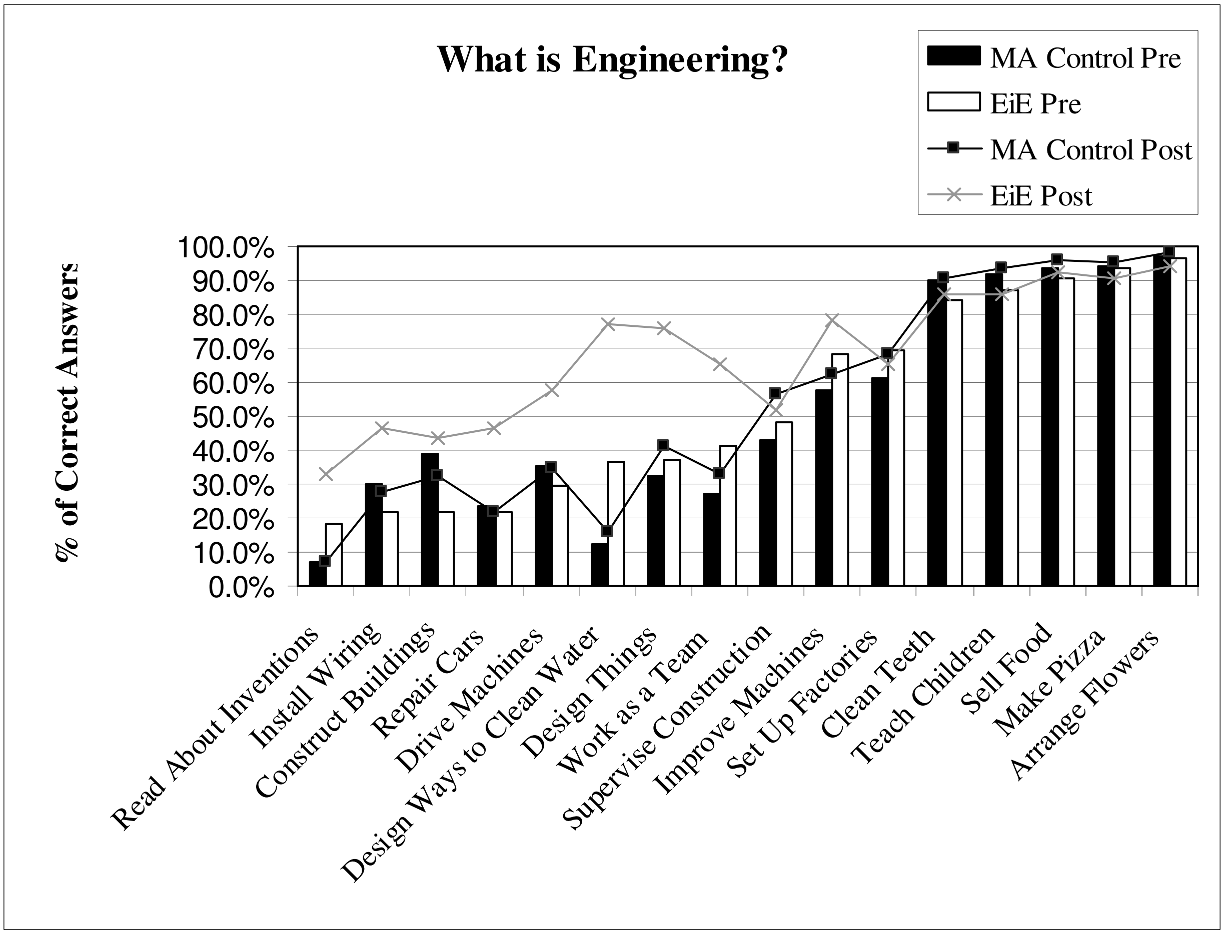
Phone	Pre	90.4%	94.0%	0.000
	Post	95.5%	97.0%	0.034
	McNemar p=	0.002	0.000	
Television	Pre	87.6%	94.2%	0.000
	Post	93.9%	93.0%	0.507
	McNemar p=	0.001	0.277	
Tree	Pre	96.0%	96.6%	0.289
	Post	98.5%	96.4%	0.024
	McNemar p=	0.064	0.488	
Bird	Pre	97.1%	97.1%	0.929
	Post	98.5%	98.5%	0.523
	McNemar p=	0.263	0.000	
Dandelions	Pre	97.1%	97.5%	0.404
	Post	98.7%	98.6%	0.706
	McNemar p=	0.263	0.000	

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 “man-made”.

What is Engineering?

The “What is Engineering?” question shows 16 kinds of work and asks which are things that engineers might do for their jobs. EiE students showed significant improvement on 10 of the 16 items from pre- to post-assessment. For eight of these items, this improvement was dramatic (between 14% and 40% overall) and significant ($p<.000$) and significantly better than the control sample ($p<.000$). On two of these items, the control sample also improved; however, control improvement was between 18% and 30% less than EiE (test) improvement. On one item—arrange flowers—EiE students were slightly (2.3%) but significantly ($p<.006$) more likely to do worse on the post- than on the pre-assessment. On two items—supervise construction and set up factories—control students showed significant improvement while EiE pre-post differences were not significant (between 9% and 11% more control students improved than test students). It is unclear why this is the case.

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.

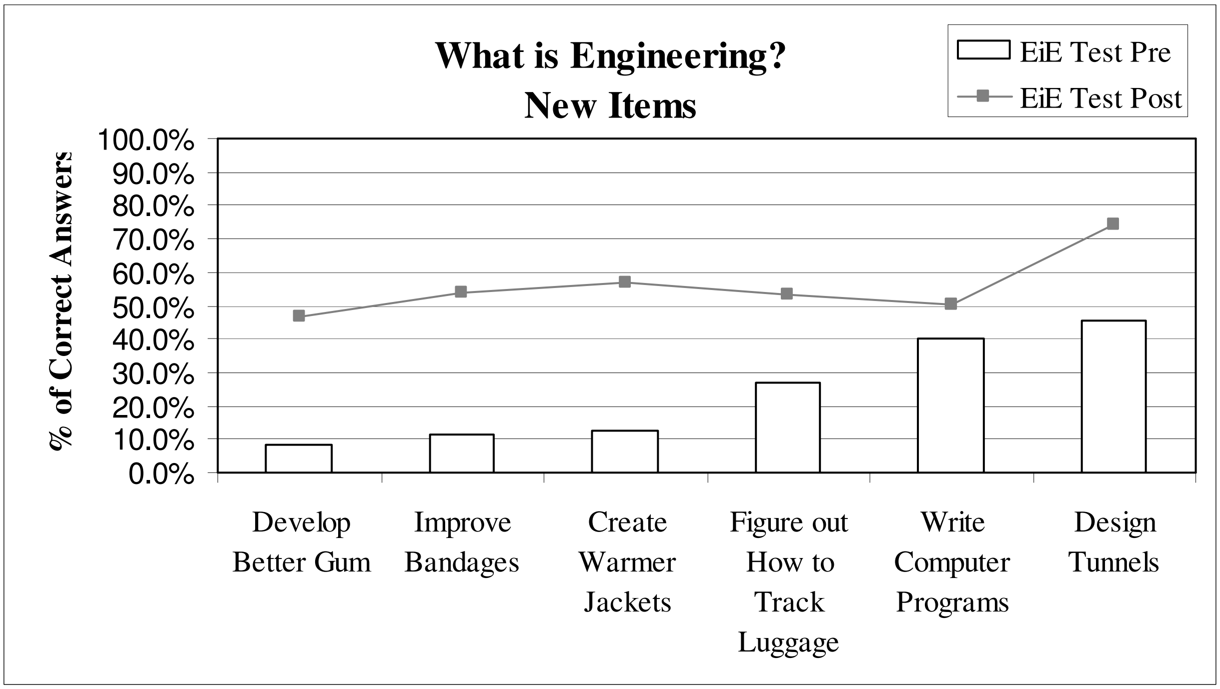


The chart below shows significant differences, marked with shading. Significant differences from pre- to post are shown in the rows marked “McNemar p=”. Significant differences between the control sample and the EiE test sample are shown in the column “Phi Coefficient p=”.

***What is Engineering?* Questions**		**Control sample: % correct**	**EiE sample: % correct**	**Phi Coefficient p=**
Read About Inventions	Pre	7.1%	18.4%	0.000
	Post	6.8%	32.7%	0.000
	McNemar p=	0.222	0.000	
Install Wiring	Pre	30.2%	21.8%	0.000
	Post	27.4%	46.4%	0.000
	McNemar p=	0.034	0.000	

Repair Cars	Pre	23.8%	22.0%	0.287
	Post	21.6%	46.7%	0.000
	McNemar p=	0.419	0.000	
Construct Buildings	Pre	38.5%	21.9%	0.000
	Post	32.3%	43.5%	0.000
	McNemar p=	0.001	0.000	
Drive Machines	Pre	35.1%	29.4%	0.001
	Post	34.6%	57.7%	0.000
	McNemar p=	0.215	0.000	
Design Ways to Clean Water	Pre	12.3%	36.6%	0.000
	Post	16.1%	76.8%	0.000
	McNemar p=	0.065	0.000	
Design Things	Pre	32.2%	36.9%	0.131
	Post	40.9%	76.2%	0.000
	McNemar p=	0.000	0.000	
Work as a Team	Pre	26.9%	41.2%	0.000
	Post	32.8%	65.2%	0.000
	McNemar p=	0.001	0.000	
Supervise Construction	Pre	42.8%	47.9%	0.113
	Post	56.2%	51.9%	0.636
	McNemar p=	0.000	0.086	
Improve Machines	Pre	57.6%	68.0%	0.001
	Post	62.1%	78.0%	0.000
	McNemar p=	0.055	0.063	
Set Up Factories	Pre	61.1%	69.4%	0.009
	Post	68.2%	65.4%	0.186
	McNemar p=	0.005	0.389	
Clean Teeth	Pre	90.1%	83.8%	0.000
	Post	90.5%	86.1%	0.018
	McNemar p=	0.500	0.013	
Teach Children	Pre	91.8%	87.1%	0.014
	Post	93.6%	86.2%	0.012
	McNemar p=	0.314	0.511	
Sell Food	Pre	93.7%	90.3%	0.002
	Post	95.9%	92.1%	0.001
	McNemar p=	0.079	0.040	
Make Pizza	Pre	93.9%	93.7%	0.881
	Post	95.6%	90.4%	0.119
	McNemar p=	0.053	1.000	
Arrange Flowers	Pre	97.0%	96.5%	0.521
	Post	98.4%	94.2%	0.000
	McNemar p=	0.263	0.006	

Some questions in the *What is Engineering?* table were new to the assessments since control data was collected, 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. These changes show a willingness to associate engineering with the design and improvement of a broader range of technologies.

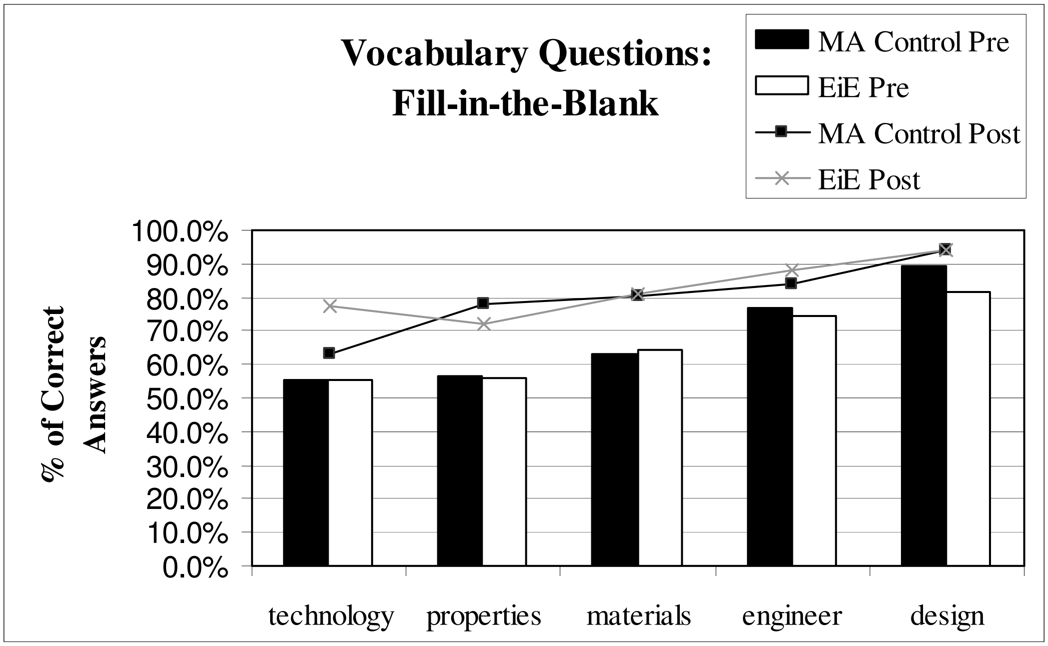


What is Engineering? **New Items**	**Pre % correct**	**Post % correct**	**McNemar p=**
Create Warmer Jackets	12.6%	56.8%	0.000
Improve Bandages	11.1%	54.0%	0.000
Develop Better Gum	8.1%	46.6%	0.000
Figure out How to Track Luggage	26.9%	53.1%	0.000
Write Computer Programs	39.8%	50.2%	0.000
Design Tunnels	45.5%	74.2%	0.000

Vocabulary Questions

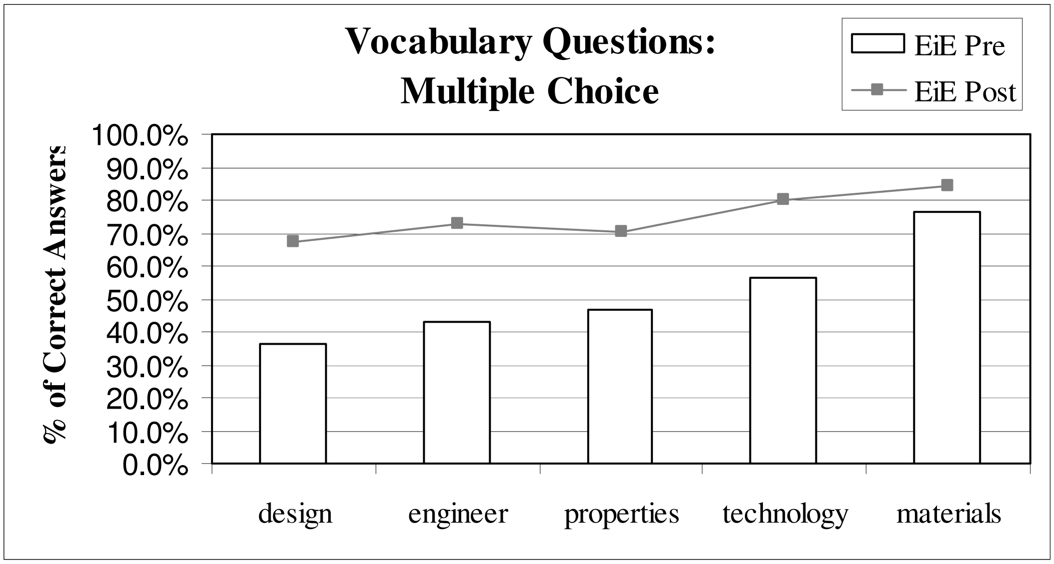
Students were asked to correctly complete sentences with engineering vocabulary words. For all sentences, they were given a list of six words to choose from. For all vocabulary words control students performed significantly better on the post-assessment than on the pre-assessment. EiE students improved 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).



Vocabulary: Fill-in-the-Blank		MA Control	EiE	McNemar p=
properties	Pre	56.7%	56.2%	0.929
	Post	78.0%	72.1%	0.598
		0.000	0.108	
materials	Pre	63.4%	64.0%	0.900
	Post	80.4%	80.9%	0.950
		0.000	0.108	
technology	Pre	55.2%	55.2%	0.997
	Post	63.0%	77.3%	0.011
		0.020	0.002	
design	Pre	89.3%	81.8%	0.035
	Post	94.0%	94.1%	0.118
		0.001	0.021	
engineer	Pre	76.5%	74.2%	0.621
	Post	83.7%	88.2%	0.179
		0.003	0.004	

A newer version of the vocabulary assessment was designed to be multiple-choice. 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. Control students did not receive these questions so there is no comparison available.



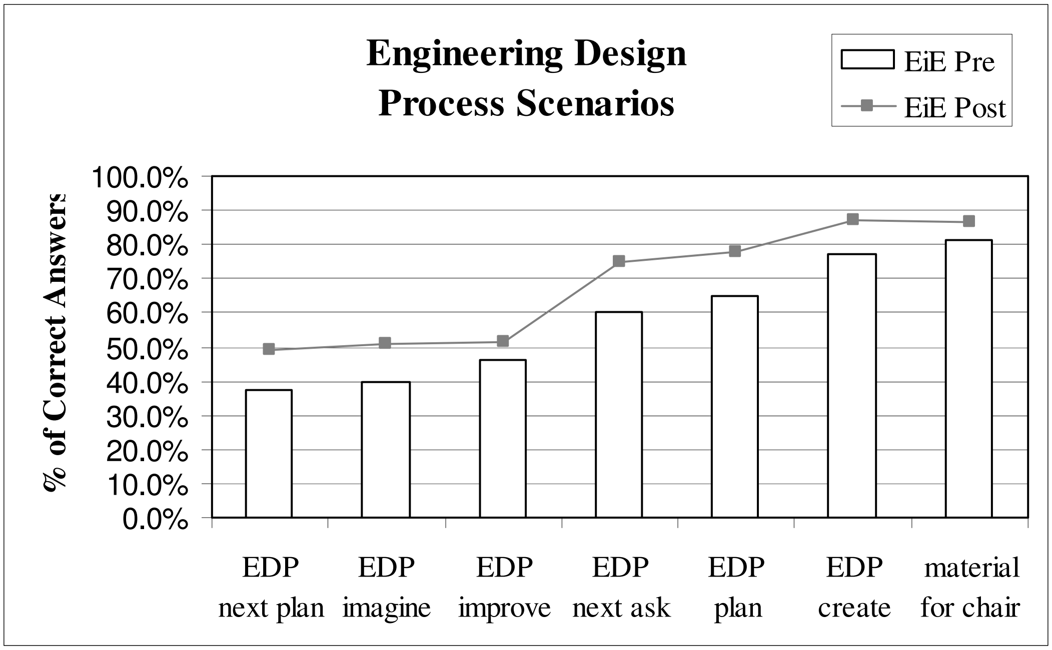
Vocabulary: Multiple Choice	**Pre**	**Post**	**McNemar p=**
properties	46.5%	70.6%	0.000
materials	76.5%	84.5%	0.000
technology	56.5%	80.2%	0.000
design	36.6%	67.2%	0.000
engineer	42.7%	72.6%	0.000

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.

Questions about the Engineering Design Process

We asked the EiE students a series of questions about the engineering design process. 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 the materials question, EiE students were significantly more likely to choose the correct answers on the post-assessment than on the pre-assessment ($p<.000$ except “EDP Next Plan” $p<.005$).

This is encouraging though not surprising given that each EiE unit is organized around the engineering design process. We are encouraged to see that students are able to apply their experience with the engineering design process to new, hypothetical situations.



Engineering Design Process Scenarios	Pre	Post	McNemar p=
EDP improve	46.3%	51.4%	0.000
EDP create	77.1%	86.9%	0.000
EDP imagine	39.8%	50.8%	0.000
EDP next plan	37.3%	49.0%	0.005
EDP next ask	60.1%	74.8%	0.000
material for chair	81.1%	86.6%	0.315
EDP plan	64.6%	77.9%	0.000

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, they tested a variety of materials for filtering particulates and chemicals from water, and they designed their own water filters.

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. A copy of a later version of the *Designing Water Filters* unit assessment can be found at the end of this paper.

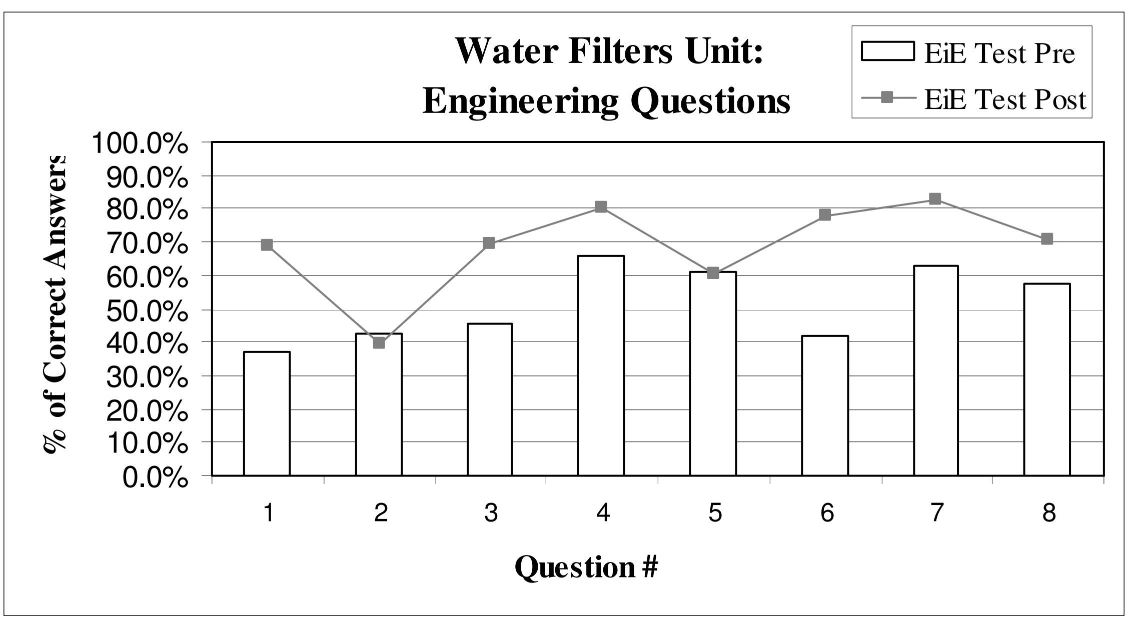
Designing Water Filters Unit Question with Control Comparison

Only one question on the Water Filters unit assessment was shared between the control sample and the test (EiE) sample. This question asked about condensation. EiE students were significantly more likely to answer this question correctly on the post-assessment than on the pre-assessment, as were control students. Control students performed significantly better on both the pre- and the post-assessments ($p<.000$). However, EiE students were significantly less likely to answer this question correctly than control students on the pre-assessment and also on the post-assessment, possibly because the states of water is an important science concept on the Massachusetts state assessment for the fifth grade; control students were all drawn from Massachusetts, while the EiE student sample was drawn nationally.

Water Filters Unit: Condensation Question		**Pre**	**Post**	**McNemar p=**
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?	MA Control	77.3%	84.9%	0.043
	EiE Test	46.7%	59.5%	0.000
	Phi Coefficient p=	0.000	0.000	

Designing Water Filters Unit Questions without Control Comparison

EiE students were asked eight questions about water filters and water filter materials. On all of these but two, students were significantly more likely to answer correctly on the post-assessment than on the pre-assessment. 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 distractor, "use soap", as NOT a way to clean water).



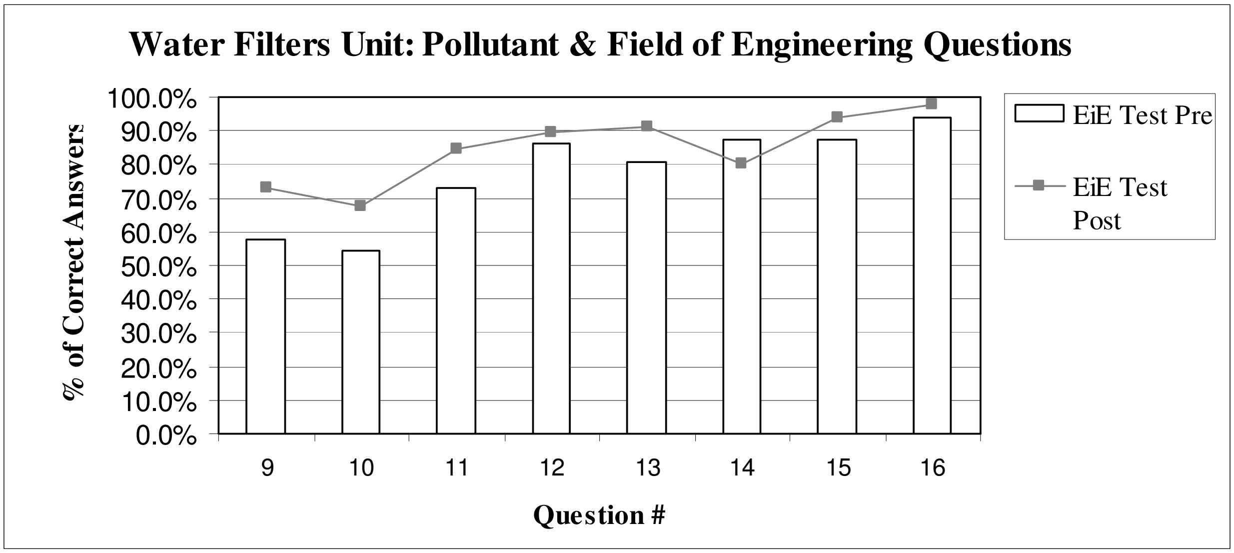
Questions 2 through 7 in particular are nearly direct assessments of what students were learning in the *Designing Water Filters* unit: students filtered out soil and corn starch, not leaves and flour, but they did test sand, paper, and screen as filter materials. Questions 1 and 8 ask about similar situations to what they were learning in the unit, but are not directly drawn from what students were doing. Student ambivalence about questions 2 and 5 is evidence of problems with the unit, which we are addressing: 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 1 and 8 show that students are transferring what they learned to new though similar situations.

Question #	Water Filters Unit: Engineering Questions N=476 (except Question#8 N=1700)	EiE Test Pre	EiE Test Post	McNemar p=
1	Which is NOT a way to make water cleaner?	36.8%	69.0%	0.000
2	Should you use this material for a leaf filter: sand	42.7%	39.8%	0.824
3	Should you use this material for a leaf filter: paper	45.5%	69.7%	0.000
4	Should you use this material for a leaf filter: screen	65.6%	80.5%	0.000
5	Should you use this material for a flour filter: sand	60.9%	60.6%	0.505
6	Should you use this material for a flour filter: paper	41.6%	77.7%	0.000
7	Should you use this material for a flour filter: screen	62.9%	82.4%	0.000
8	What material would be best to use for a pool net?	57.6%	70.9%	0.000

EiE students were also asked questions about the kinds of work done by environmental engineers, and about items that might contribute pollutants to the air. Three of the four questions about engineering work (questions 9-11) showed significant improvement; the fourth (question 12) showed a ceiling effect (almost 90% correct both pre- and post-). Three of the four questions about pollutants (#'s 13-16) showed significant improvement ($p<.000$ except $p<.011$ for #15). The only exception was question #14, asking about whether a dog could add pollutants to the air. We have decided this question is problematic, since dogs (like cows, which are sometimes discussed in lesson 2 of the Water Filters unit) do release tiny amounts of methane, which is a pollutant in large quantities.

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.

The fact that students find the questions about pollutants (#'s 13-16) easy to answer correctly on both the pre- and post-assessment suggests that students may need a more challenging lesson on the topics provided than is currently presented in the unit.

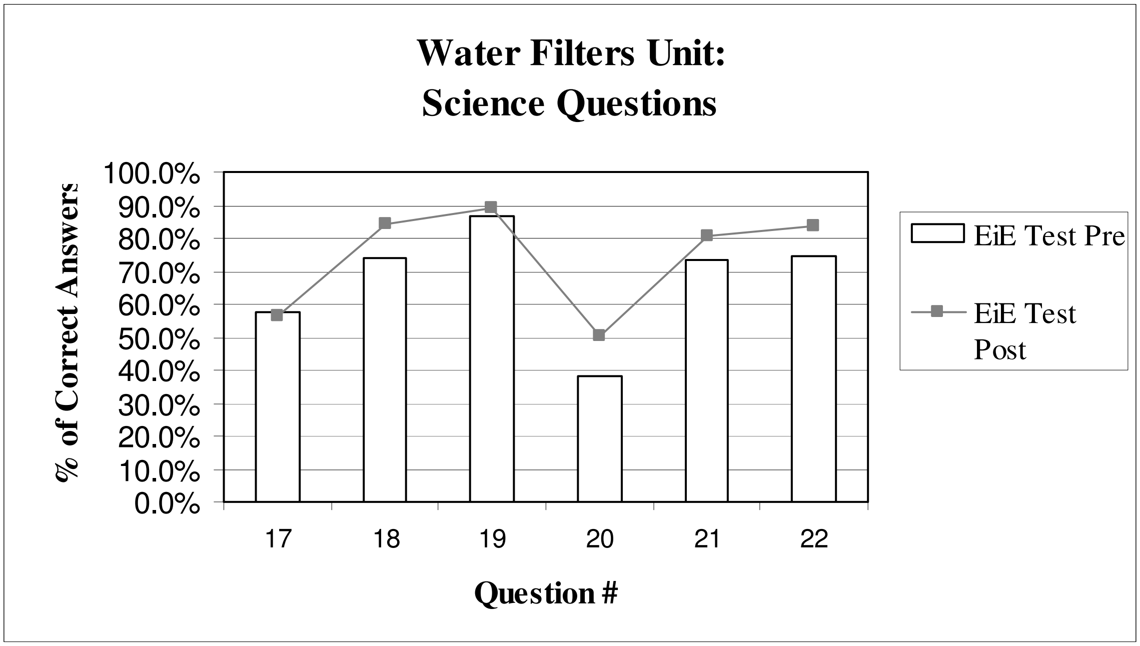


Question #	Water Filters Unit: Pollutant & Field of Engineering Questions	EiE Test		
	N=491	**Pre**	**Post**	**McNemar p=**
9	Environmental engineer stops harmful plants	57.6%	73.1%	0.000
10	Environmental engineer rescues dolphins	54.3%	67.4%	0.000
11	Environmental engineer decides how to clean air	73.1%	84.7%	0.000
12	Environmental engineer sorts river rocks	86.0%	89.8%	0.278
13	CAR could add pollutants to air	80.5%	91.2%	0.000
14	DOG could add pollutants to air	87.5%	80.0%	0.000
15	WATERFALL could add pollutants to air	87.2%	93.9%	0.011
16	FACTORY could add pollutants to air	94.0%	97.6%	0.008

Designing Water Filters Science Content Questions

The remaining six questions for the Water Filters unit are science content questions. 454 students answered these questions. EiE students showed significant improvement on three of these questions. Of the three which did not show improvement, question #19 "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 #17 ("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.

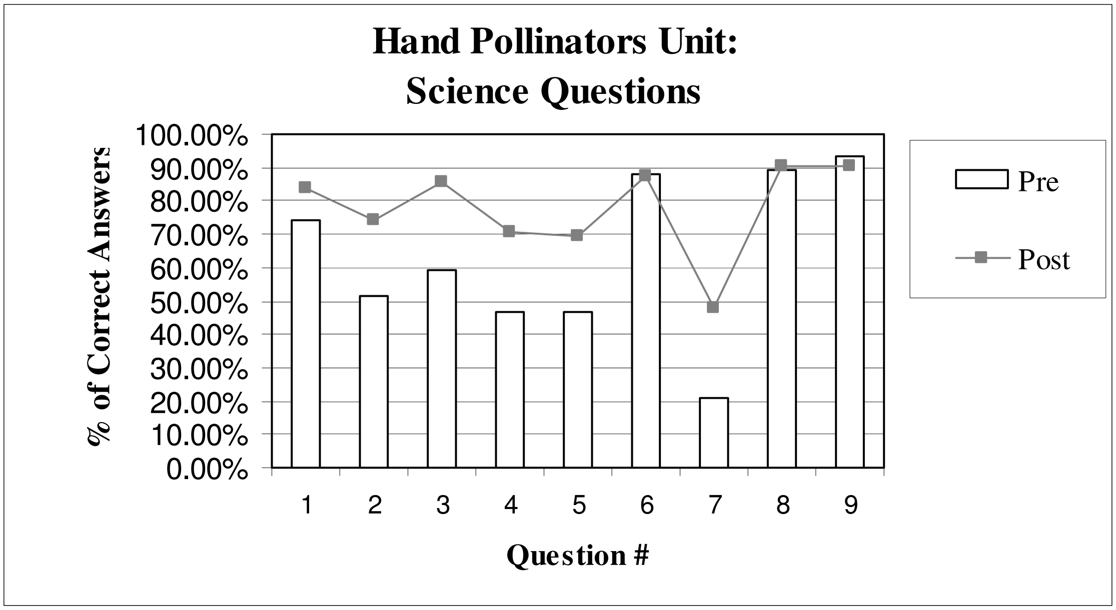


Question #	Water Filters Unit: Science Questions	Pre	Post	McNemar p=
17	Earth has limited fresh water	57.6%	56.2%	0.407
18	Condensation is part of the water cycle	73.9%	84.4%	0.012
19	Water disappears forever when it evaporates	86.5%	89.0%	0.470
20	The water cycle makes new water	38.2%	50.3%	0.001
21	Frozen water is no longer contaminated	73.3%	80.4%	0.062
22	Water can be a solid, liquid, or gas	74.2%	83.4%	0.000

Results for the Designing Hand Pollinators Unit Questions

Hand Pollinators Unit: Science Questions

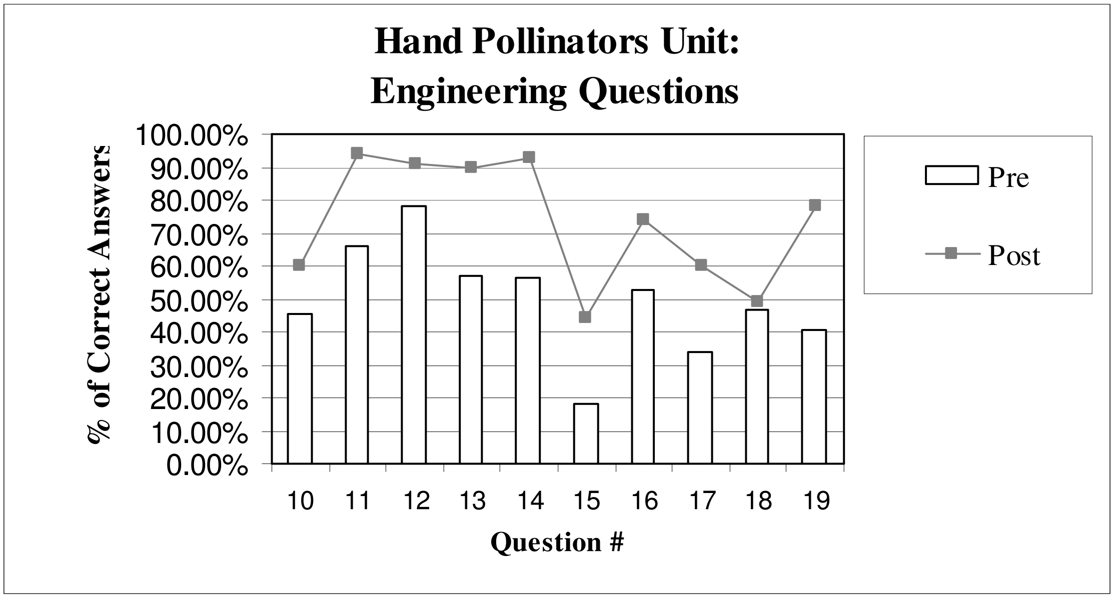
On all science questions for the Hand Pollinators Unit, EiE students either improved significantly (p<.000) or the pre-assessment performance was too high (>88% correct) to permit significant change. Students were asked a series of questions about the roles of insects, plants, and parts of plants in the pollination process. Students were also asked to identify whether sunlight, insects, people, and water are needed by plants to grow and make seeds. All of the questions regarding the survival needs of plants were too easy for students except for the question regarding insects.



Question #	Hand Pollinators Unit: Science Questions	Pre	Post	McNemar p=	N
1	If Mario kills wasps, what will probably happen?	74.2%	84.1%	0.000	737
2	Do first to make sure insects won't hurt plants:	51.6%	74.3%	0.000	732
3	Insects are useful to plants because they:	59.1%	85.4%	0.000	247
4	Which part of this plant is NOT part of the pollination system?	46.6%	70.7%	0.000	249
5	Why do insects like bees visit flowers?	46.6%	69.5%	0.000	118
6	Most plants need SUNLIGHT to grow and make seeds	88.2%	87.3%	0.709	567
7	Most plants need INSECTS to grow and make seeds	21.2%	47.8%	0.000	567
8	Most plants need PEOPLE to grow and make seeds	89.4%	90.5%	0.581	567
9	Most plants need WATER to grow and make seeds	93.3%	90.3%	0.071	567

Hand Pollinators Unit: Engineering Questions

EiE students (N=269) also improved significantly (p<.000 except p<.001 for question #10) on all engineering questions but one (question #18) for the Hand Pollinators Unit. Students were asked to consider four different things and mark those that they would consider in designing a hand pollinator. On the post-assessment, they were much more likely (14%-33% improvement) to say that they should consider the shape of the flower, whether the pollinator material can pick up pollen, and whether the material can drop off pollen. They were much less likely (12%) to say that they should consider the color of the flower. When asked about how they should pollinate flowers in their garden if the pollinating insect is not available, 93% of students answered on the post-assessment that they would use a hand pollinator (a 36% increase). Questions 15-19 asked about things that agricultural engineers might do for their jobs. Students showed significant improvement (21-38%) on all of these questions except for "figure out the best way to water fields", which was not directly discussed in the unit.



Question #	Hand Pollinator Unit: Engineering Questions	Pre	Post	McNemar p=
10	Consider SHAPE OF FLOWER when designing a hand pollinator?	45.6%	59.8%	0.001
11	Consider COLOR OF FLOWER when designing a hand pollinator?	66.0%	93.8%	0.000
12	Consider IF MATERIAL CAN PICK UP POLLEN when designing a hand pollinator?	78.4%	90.7%	0.000
13	Consider IF MATERIAL CAN DROP OFF POLLEN when designing a hand pollinator?	57.1%	89.6%	0.000
14	BEST way to pollinate flowers if insects are not available:	56.3%	92.7%	0.000
15	An agricultural engineer's job could involve:	18.4%	44.1%	0.000
16	Agricultural engineers might KEEP INSECTS FROM EATING CROPS	52.8%	74.0%	0.000
17	Agricultural engineers might POLLINATE FOOD PLANTS	33.8%	59.9%	0.000
18	Agricultural engineers might FIGURE OUT BEST WAY TO WATER FIELDS	46.5%	49.1%	0.608
19	Agricultural engineers might DRIVE A TRACTOR TO HARVEST FOOD	40.7%	78.4%	0.000

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 and their use in different water filtration scenarios after completing the *Designing Water Filters* unit.
- Are much more likely to correctly identify the work of environmental engineers on the post-assessment after completing the *Designing Water Filters* unit.
- Are much more likely to correctly answer science content questions relating to water after completing the *Designing Water Filters* unit.
- Demonstrate a clearer understanding of the criteria for judging the effectiveness of a hand pollinator design after completing the *Designing Hand Pollinators* unit.
- Are much more likely to correctly identify the work of agricultural engineers after completing the *Designing Hand Pollinators* unit.

EiE students demonstrated on the post-assessment for the *Designing Water Filters* unit 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

Our next steps will be to analyze data for the remaining eight units for which we have collected data. 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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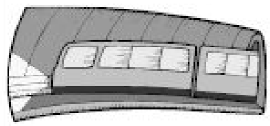
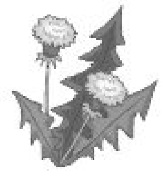
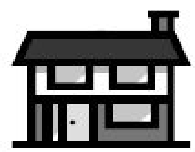
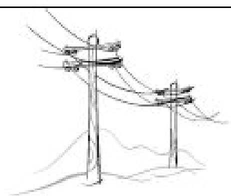
What is Technology?

Which of these things are examples of technology?
Circle all of the items that you think are technology.

 Shoes	 Subway	 Dandelions	 Cellular Phone
 Oak Tree	 Bridge	 Television	 Cup
 Bird	 Factory	 Bandage	 House
 Power Lines	 Bicycle	 Lightning	 Books

How do you know if something is technology?

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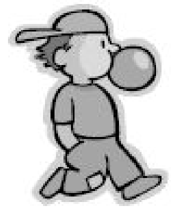
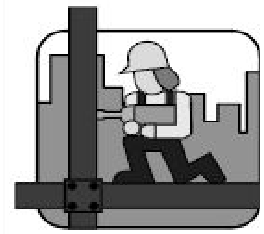
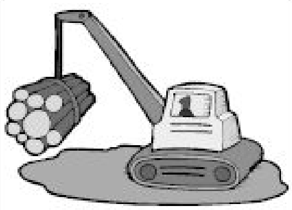
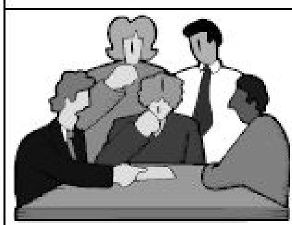
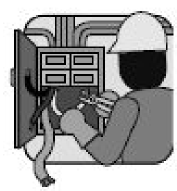
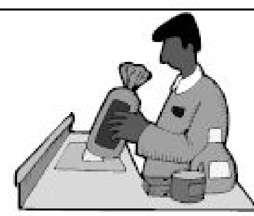
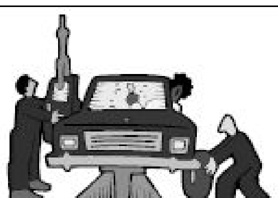
What is an Engineer?

What kinds of work do engineers do?

Circle the kinds of work that you think engineers do for their jobs.

 Improve Bandages	 Develop Better Bubble Gum	 Design Ways to Clean Water	 Construct Buildings
 Drive Machines	 Arrange Flowers	 Read About Inventions	 Figure Out How to Track Luggage
 Work as a Team	 Create Warmer Kinds of Jackets	 Install Wiring	 Sell Food
 Repair Cars	 Design Tunnels	 Clean Teeth	 Write Computer Programs

What is an engineer?____

____

____

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Vocabulary Check!

Complete each of the sentences below by circling the BEST choice of the words in **BOLD**.

1. Some **materials/properties/designs** of a piece of wood are how strong it is and how smooth it is.

2. Some **materials/properties/designs** that can be used to make roads are concrete, flat rocks, tar, and gravel.

3. **Technology/Science/Design** is anything that people make to solve a problem.

4. When you **use/design/build** a chair, you need to think about how big and how strong it needs to be.

5. **Scientists/Engineers/Artists** are people who solve problems using math, science, and imagination.

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Printed 11/21/2005

1. David and Sonali are working on a design. They are making this list. Which step of the engineering design process are they working on? Circle **ONE** answer.

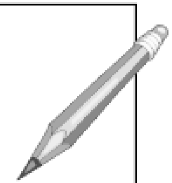
A. Ask

B. Plan

C. Create

D. Improve

Things we could do to make
our assembly line work faster:
-Make the lever longer
-Put the simple machines closer
together
-Attach another bucket to the cart



2. 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 of the Engineering Design Process do you think Dana and Leif were working on? Circle **ONE** answer.

A. Ask

B. Imagine

C. Plan

D. Create

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1. Yi Min and Chen were talking about how to mix earth materials to make a strong mortar. Yi Min suggested mixing sand and straw with water. Chen suggested mixing clay and straw, because clay is sticky. They continued to think of more ideas.

   Which step of the Engineering Design Process do you think Yi Min and Chen were working on? Circle **ONE** answer.

   A. Ask

   B. Imagine

   C. Plan

   D. Create

2. What step of the Engineering Design Process would Yi Min and Chen do **next**? Circle **ONE** answer.

   A. Ask

   B. Imagine

   C. Plan

   D. Create

3. Antoine and Sara are working on a design. They are making this list. Which step of the engineering design process are they working on?

   A. Ask

   B. Imagine

   C. Plan

   D. Create

What is the problem?
What materials can we use?
How have other people solved this problem?

1. 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.

2. If you want to build a filter that gets leaves out of water, what materials should you use? Check **ALL** materials that would work.

   ☐ Sand filter

   ☐ Paper filter

   ☐ Metal screen

3. If you want to build a filter that gets flour out of water, what materials should you use? Check **ALL** materials that would work.

   ☐ Sand filter

   ☐ Paper filter

   ☐ Metal screen

4. 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?

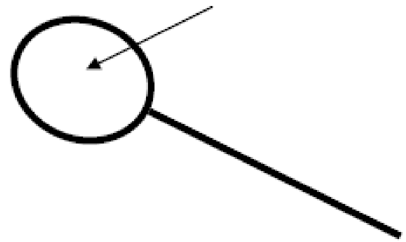
   A. It rained.

   B. It condensed.

   C. It evaporated.

   D. It froze.

1. 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. A sheet of plastic.

   B. A piece of cloth.

   C. A piece of paper.

   D. A piece of wood.

2. Nathan is an environmental engineer. Check **ALL** of the things that Nathan might do for his job.

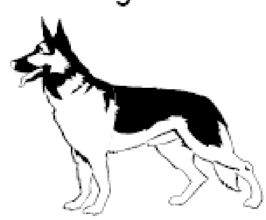
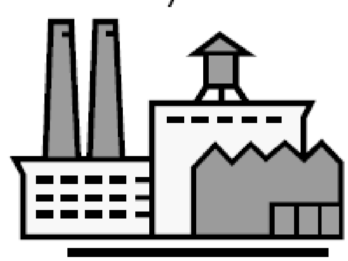
   ☐ Stop harmful plants from growing in a lake.

   ☐ Rescue dolphins from fishing nets.

   ☐ Decide methods for cleaning air.

   ☐ Sort river rocks by size.

3. Check **ALL** of the things that could add pollutants to the air.

☐ Car 	☐ Dog 
☐ Waterfall 	☐ Factory 

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Decide which of the following statements are true or false.

Mark "T" for true or "F" for false for each statement.

T F	1. The earth has a limited amount of fresh water.
T F	2. Condensation is part of the water cycle.
T F	3. Water disappears forever when it evaporates.
T F	4. The water cycle makes new water.
T F	5. If polluted water freezes, it is no longer contaminated.
T F	6.Water can be a solid, liquid, or gas.

Version 10/18/2005
Printed 11/21/2005

1. Melissa is designing a hand pollinator. Look at the list below. Check **ALL** of things she should consider when she designs her hand pollinator.

- ☐ The shape of the flower.
- ☐ The color of the flower.
- ☐ If the hand pollinator can pick up pollen.
- ☐ If the hand pollinator can drop off pollen.

2. 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.

3. If you are an agricultural engineer, your job could involve

   A. fixing tractors.

   B. driving tractors.

   C. planting crops.

   D. figuring out how to control pests.

1. 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.

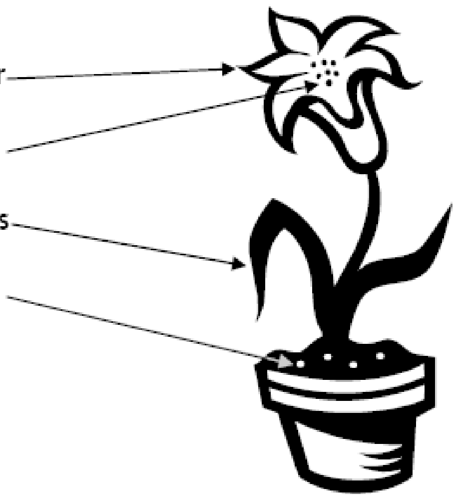
2. Which part of this plant is NOT part of the pollination system?

    A. Flower

    B. Pollen

    C. Leaves

    D. Seeds



3. Look at the list below. Check **ALL** of the things that agricultural engineers do for their work.

- ☐ Keep insects from eating crops.
- ☐ Pollinate plants we use for food.
- ☐ Figure out the best way to water fields.
- ☐ Drive a tractor that harvests food.

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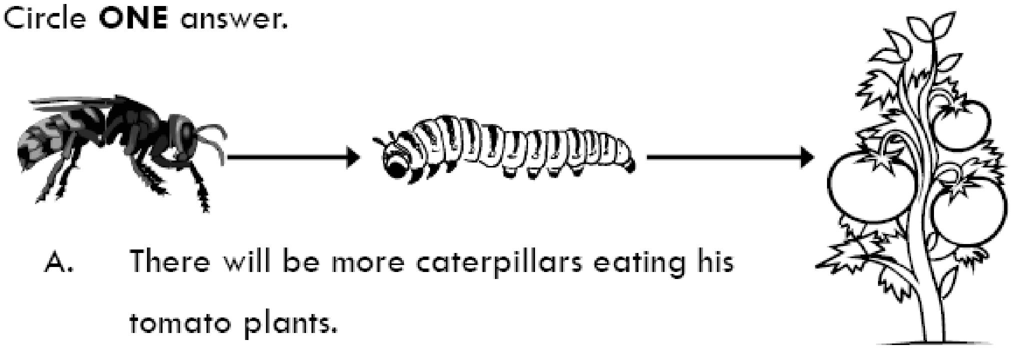
1. Paper wasps eat caterpillars. Caterpillars eat tomato plants. If Mario kills the paper wasps in his garden, what will probably happen? Circle **ONE** answer.



   A. There will be more caterpillars eating his tomato plants.

   B. There will be fewer caterpillars eating his tomato plants.

   C. There will be more wasps in his garden.

   D. Nothing will change in the garden.

2. 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.

3. 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