Engineering our Future New Jersey:
Evaluation of the Implementation of Elementary Curricula

Dr. Cathy P. Lachapelle
Engineering is Elementary
The National Center for Technological Literacy
Museum of Science, Boston
February 16, 2007

Executive Summary

Overview

Engineering Our Future New Jersey (EOFNJ) is a collaborative effort led by the Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology. The goal of the EOFNJ initiative is to bring exemplary and innovative technology and pre-college engineering curricula to mainstream New Jersey K-12 education, with the eventual goal being to introduce age-appropriate engineering and technology education to all New Jersey grade school students. Thirty-five teachers from a diverse sample of 32 New Jersey elementary, middle and high schools participated in the 2005-2006 CIESE pilot study. Thirteen of the 35 teachers participated in the elementary-grade portion of the pilot study.

This evaluation concerns the implementation of engineering and technology education in the elementary grades. Thirteen teachers and their approximately 400 students in grades 3 through 5 from 20 classrooms in 12 schools participated in pilot testing engineering curricula for the elementary grades. These teachers attended a two-day professional development workshop in December 2005 at Stevens Institute of Technology. During the hands-on workshop they discussed age-appropriate teaching of engineering and technology topics to elementary children, and they reviewed and experimented with two engineering units from the *Engineering is Elementary* (EiE) curriculum. The thirteen participating teachers each implemented one or both of these two units in their classrooms.

Engineering is Elementary is a curriculum project which has produced, as yet, ten (of twenty planned) supplemental engineering/technology units designed to be integrated with science instruction in the elementary grades. Each unit begins with a story to set the context, includes a lesson illustrating a field of engineering, and ends with a design challenge for students. Each unit also includes materials and "teacher tips" for how to integrate the units with literacy, mathematics, and social studies instruction. The story and the design challenge are each chosen to illustrate themes from the International Technology Education Association (ITEA) standards for technological literacy, and to illustrate a field of engineering.

The two units chosen for the first year of New Jersey pilot testing were *Water, Water Everywhere: Environmental Engineering and Designing Water Filters* and *Catching the Wind: Mechanical Engineering and Designing Windmills.* The *Designing Water Filters* unit is designed to be taught in conjunction with science instruction about water and the water cycle. The design challenge is set in the context of water filtration and purification issues in India. The *Designing*

Windmills unit is set in Denmark, where wind turbines are common and wind power provides a large portion of electrical power; it is designed to be taught in conjunction with the science of weather, wind, and (for more advanced grades) energy.

The Study

The EiE team at the Museum of Science, Boston conducted the evaluation of student learning resulting from use of the EiE units. This evaluation is part of EiE's ongoing national research effort to assess the impact of EiE units on student learning of engineering, technology, and science concepts. In New Jersey, the evaluation study is based upon pre-assessments which were distributed by teachers to students before beginning any EiE units or associated science content and post-assessments which teachers gave to students after they completed the EiE units and associated science content. Pre- and post- assessments contain identical assessment items. The three pre-post assessments administered to students included "General Engineering and Technology Questions", which was given to all students; "Water Filter Unit Questions" which was given to students completing the *Designing Water Filters* unit; and "Designing Windmills Unit Questions" which was given to students working on the *Designing Windmills* unit.

Student performance on the pre-assessments was compared to student performance on the post-assessments. The differences pre- to post- were analyzed for statistical significance. Where possible, New Jersey student responses were compared to responses from a comparable control sample of Massachusetts students. The control sample was a group of students who completed a set of pre-assessments in November of the 2004-2005 school year and matching post-assessments in June 2005 of the same school year without having completed any EiE units or having had other engineering/technology instruction. Control assessments included many of the same questions as the NJ assessments but were not identical. Assessments were collected from the control sample in order to have a measurement of improvement pre- to post- due to maturation. The difference between control and NJ EiE samples gives a truer sense of the improvement due to participation in EiE units. Though the samples were different in some demographics—a larger proportion of the control sample receives free or reduced lunch, and also a larger proportion of the control sample does not have English as their primary language—post-hoc examination of the data has not shown evidence of interaction effects.

Key Findings

General Engineering and Technology Questions

For the "What is Technology?" assessment, students were asked to identify items that were technology from 16 items presented. On the 9 more difficult items to classify—items such as Cup, Bandage, Shoes, and Lightning—NJ EiE students improved dramatically (between 11% and 50% overall) 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, NJ EiE students improved significantly ($p<.000$) more than the control sample.

The "What is Engineering?" assessment showed 16 kinds of work and asked which were things that engineers might do for their jobs. New Jersey EiE students showed significant improvement on 12 of the 16 items from pre- to post-assessment. Again, this improvement was dramatic (between 16% and 48% overall) and significant ($p<.000$) and significantly better than the control sample ($p<.000$). On three of the remaining items, students were slightly but significantly more likely to do worse (between 5% and 6% overall) on the post- than on the pre-assessment—Arrange Flowers ($p<.002$), Sell Food ($p<.005$) and Clean Teeth ($p<.023$)—this appears to be due to a slight tendency of students having completed the program to think that engineers do "everything". These results are also significantly different from the control sample, which did not change significantly on these items.

When asked to correctly complete sentences with vocabulary words (multiple choice), students participating in EiE were significantly more likely ($p=.000$) to choose the correct vocabulary word on the post-assessment than on the pre-assessment. Students were also given a series of questions, each of which presented a scenario where children were designing something, and asked which step of the engineering design process those children were engaged in or would proceed to next. On all questions, students were significantly more likely to choose the correct answers on the post-assessment than on the pre-assessment. No control comparison is available for these items.

Designing Water Filters Unit Questions

The *Designing Water Filters* unit challenges students to design a filter that will remove large particulates (soil), small particulates (corn starch) and chemicals (tea) from water. Students experiment with a variety of filter materials including metal screens, paper coffee filters, and a column of sand. The story addresses some aspects of the water cycle as well as basic ideas in water purification and the role of environmental engineers. Lesson 2 of the unit addresses the concept of pollutants and what aspects of human activity add to pollution of soil, air, and water.

The assessment for this unit asked eight questions about water filtration and the materials used to filter different kinds of contaminants from water. New Jersey EiE students significantly improved in their answers to six of the eight questions. They significantly improved in their responses to two of four questions asked about the work of environmental engineers. Of four questions about pollutants, three proved to be too easy for students (more than 90% answered correctly on both the pre- and post-assessments), while one of the four was discarded as a poor question. Of seven questions about the science of water and the water cycle, New Jersey EiE students showed significant improvement on five; one question was ambiguous and so results were discarded; the seventh question was too easy for students (89% answered correctly on the pre-assessment).

Designing Windmills Unit Questions

For the *Designing Windmills* unit, students learn about the work of mechanical engineers. They also learn to apply the science concept that wind is air that can move things, and that energy in one form can be transformed and used. In one lesson, they design sails for moving a "boat" along a string track; and in the culminating lesson they are challenged to design the blades for a small windmill such that they will get enough power from the wind (a fan) to lift a weight.

New Jersey EiE students performed consistently better on the post-assessment for the *Designing Windmills* unit than on the pre-assessment, but not all changes pre- to post- were significant. One question about tools used to observe the wind appears to have been too difficult for students, while six questions about technologies that use the wind were too easy for students, with over 90% of students answering the pre-assessment correctly for four out of five items. On the remaining six items—all of which were "engineering" content questions—New Jersey EiE students showed statistically significant improvement.

Conclusions

New Jersey 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, NJ EiE students have, in almost every instance, performed significantly better than the control students. Specifically, NJ EiE students:

- Demonstrate a much clearer understanding of technology as human-made—regardless of whether it is "modern" or uses electrical power.
- Demonstrate a much clearer understanding of the work of engineers as involving design and teamwork: not everyone who works with engines or electricity is an engineer, and engineers work to improve the environment and medicines, not just cars and computers.
- 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 uses in similar scenarios after completing *Engineering is Elementary* units.
- Are much more likely to correctly identify the work of environmental engineers on the post-assessment after completing the *Designing Water Filters* unit, and of mechanical engineers after completing the *Designing Windmills* unit.
- Are much more likely to correctly answer science content questions relating to water after completing the *Designing Water Filters* unit.

The goals of engineering education in the elementary grades include giving students a taste of the enormous variety of technologies and designs on which engineers work, and introducing 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.
- Familiarity with materials and 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.
- 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 research presented here gives strong evidence that many of these goals are being met in New Jersey by the *Engineering is Elementary* curriculum.

Detailed Analysis

The Samples

Where possible, student responses (called NJ EiE or Test below) were compared to responses from a comparable control sample. EiE responses were drawn from New Jersey. 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 received free or reduced lunch—preliminary post-hoc examination of the data has not shown evidence of interaction effects.

Sample Size

We are working with a sample size of 345 EiE students from New Jersey and 1073 control students from Massachusetts. Each EiE New Jersey student did a complete General Engineering assessment, as well as all questions from the Water Filters and Windmills units. Each control student did 1/3 of the General Engineering assessment (questions randomly assigned), and only some students answered Water Filters questions. The Windmills questions were assigned to grade 2 students for the control sample, and were not used to compare against the grade 4 and 5 students from New Jersey.

Grade

I chose to run the comparison using only grades 4 and 5. We have no grade 2 data from New Jersey, and only 41 grade 3 students, while the control population had a majority of grade 3 students. By limiting the comparison to grades 4 and 5, the distribution across grades became proportionally more similar, though the difference was still statistically significant (Nominal by Interval Eta p=.144).

Crosstab

			Grade		Total
			Grade 4	Grade 5	
Population	MA Control	Count	515	558	1073
		% within Population	48.0%	52.0%	100.0%
	NJ	Count	150	195	345
		% within Population	43.5%	56.5%	100.0%
Total		Count	665	753	1418
		% within Population	46.9%	53.1%	100.0%

Gender

Gender differences were insignificant, 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). 67.5% of the control sample receives free or reduced lunch, while only 18.0% of the New Jersey EiE sample does.

Primary Language

26.4% of the control students had a language other than English as their primary language. 15.4% of New Jersey EiE students had a primary language other than English. This difference is significant (Goodman & Kruskal Tau-b p=.000).

Race/Ethnicity

Significant differences in racial makeup between the control and the New Jersey EiE samples exist (Goodman & Kruskal Tau-b p=.000). The control sample has proportionally more white students (79.6% versus 63.6%) and black students (8.6% versus 6.5%). The New Jersey EiE sample has larger proportions of Asian (12.6% versus 4.5%) and Hispanic (13.2% versus 6.6%) students.

Crosstab

		Population				Total	
		MA Control		NJ			
		Count	% within Population	Count	% within Population	Count	% within Population
Race/ Ethnicity	Black/African/ African American	92	8.6%	22	6.5%	114	8.1%
	Indian Asian	0	.0%	17	5.0%	17	1.2%
	Central/ Southeast/East Asian	48	4.5%	26	7.6%	74	5.3%
	Multiracial	0	.0%	1	.3%	1	.1%
	White/ Caucasian	849	79.6%	217	63.6%	1066	75.7%
	White Hispanic/ Latino(a)	70	6.6%	45	13.2%	115	8.2%
	Native American	7	.7%	9	2.6%	16	1.1%
	Pacific Islander	1	.1%	4	1.2%	5	.4%
Total		1067	100.0%	341	100.0%	1408	100.0%

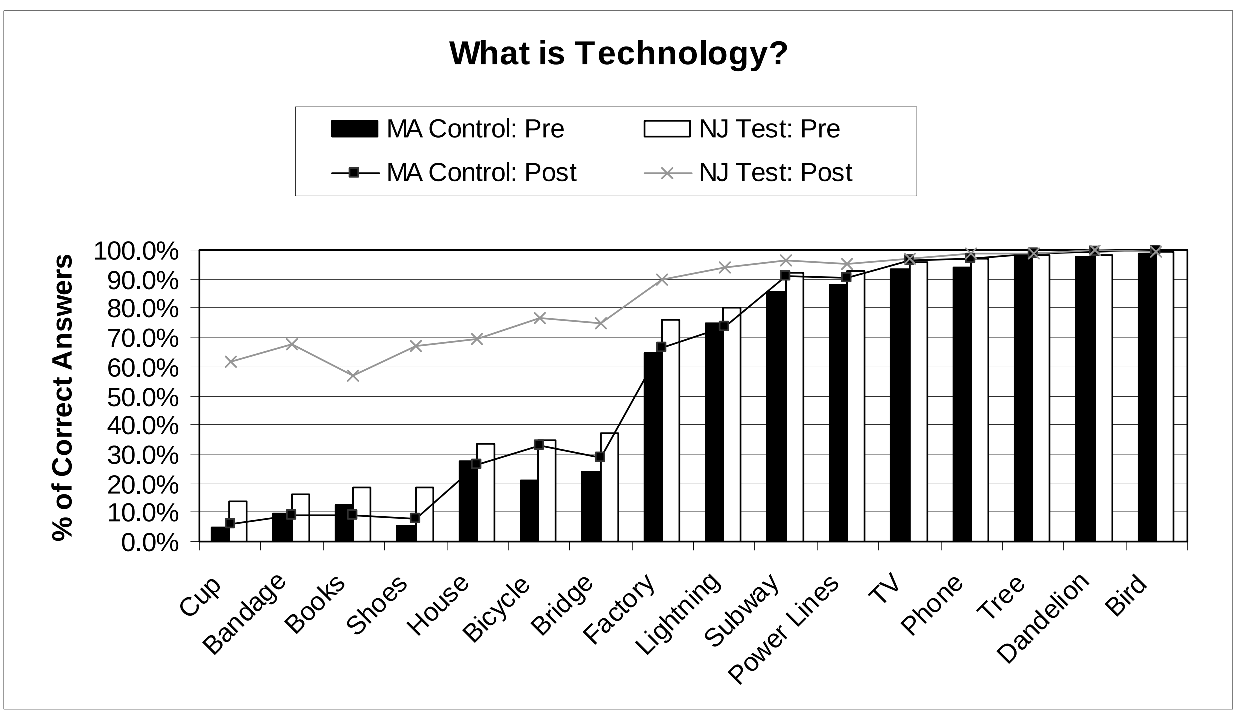
Both the New Jersey EiE sample and the control sample represent diverse cross-sections of their communities. Results drawn from these samples can be reasonably assumed to be applicable to the general population.

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 (New Jersey 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. The full text of all assessments can be found in the appendices.

What is Technology?

For the "What is Technology?" question, students were asked to identify 12 items that were technology from 16 items presented. These items are shown in the chart below, ordered by the percentage of NJ EiE students who correctly classified them as technology (or not) on the pre-assessment. The first 9 items were the most difficult for students to classify: cup, bandage, books, shoes, house, bicycle, bridge, factory, and lightning. On these 9 items, EiE students improved dramatically (between 14% and 51%) and significantly (McNemar Test of Symmetry p<.000) in their ability to correctly identify distinguish human-made items as examples of technology from natural items on the post-assessment. On these 9 items, EiE students also improved significantly (p<.000) more than the control sample. Of particular interest is "lightning", which nationally has proved surprisingly difficult for elementary students to classify—they often identify it as "technology" because of its connection to electricity. 320 control students and 194 New Jersey EiE students completed this question.



The table below 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 typeface. "Neither correct" is the percentage of students who answered incorrectly on both the pre- and the post-assessments; "both correct" is the percentage of students who answered correctly both times; "regressed" is the percentage of students who answered correctly on the pre- but incorrectly on the post-; and "improved" is the percentage of students who answered incorrectly on the pre- but correctly on the post-assessment. Significant differences from pre- to post are calculated using McNemar's Test of Symmetry. Significant differences between the control sample and the NJ EiE sample are shown in the right-most columns and are calculated using the Phi Coefficient.

What is Technology?		**Neither correct**	**Both correct**	**Regressed**	**Improved**	**Pre*Post Differences: McNemar p=**	**control * Test Differences:** Within Pre Phi p=	**control * Test Differences:** Within Post Phi p=
Cup	control	90.9%	0.9%	3.1%	5.0%	0.327	**0.000**	**0.000**
	NJ EiE	36.9%	14.0%	1.4%	47.8%	**0.000**		
Bandage	control	84.4%	2.2%	6.3%	7.2%	0.761	**0.007**	**0.000**
	NJ EiE	31.3%	16.0%	1.4%	51.4%	**0.000**		
Books	control	82.6%	1.6%	8.8%	6.9%	0.480	**0.030**	**0.000**
	NJ EiE	39.6%	16.4%	3.4%	40.6%	**0.000**		
Shoes	control	90.0%	1.3%	3.1%	5.6%	0.185	**0.000**	**0.000**
	NJ EiE	30.6%	18.0%	2.4%	49.0%	**0.000**		
House	control	57.8%	10.0%	16.6%	15.6%	0.844	0.057	**0.000**
	NJ EiE	26.2%	30.6%	3.7%	39.5%	**0.000**		
Bicycle	control	55.5%	8.5%	10.7%	25.4%	**0.000**	**0.000**	**0.000**
	NJ EiE	21.8%	34.0%	2.0%	42.2%	**0.000**		
Bridge	control	58.1%	9.1%	13.8%	19.1%	0.118	**0.000**	**0.000**
	NJ EiE	21.8%	34.4%	4.1%	39.8%	**0.000**		
Factory	control	17.5%	47.2%	15.0%	20.3%	0.132	**0.001**	**0.000**
	NJ EiE	5.8%	73.5%	4.8%	16.0%	**0.000**		
Lightning	control	11.6%	60.8%	13.8%	13.8%	1.000	0.072	**0.000**
	NJ EiE	3.4%	79.3%	2.7%	14.6%	**0.000**		
Subway	control	3.4%	82.1%	3.8%	10.7%	**0.002**	**0.004**	**0.002**
	NJ EiE	1.4%	90.1%	2.0%	6.5%	**0.015**		
Power Lines	control	1.6%	81.2%	7.2%	10.0%	0.281	**0.033**	**0.018**
	NJ EiE	1.4%	88.7%	3.4%	6.5%	0.136		
Television	control	0.0%	91.3%	3.4%	5.3%	0.345	0.623	0.112
	NJ EiE	0.3%	92.9%	2.7%	4.1%	0.503		
Phone	control	0.9%	92.5%	1.6%	5.0%	**0.027**	0.993	0.799
	NJ EiE	0.0%	96.6%	1.0%	2.4%	0.344		
Tree	control	0.0%	97.8%	0.9%	1.3%	1.000	0.993	0.799
	NJ EiE	0.0%	96.6%	1.4%	2.0%	0.754		
Dandelion	control	0.3%	97.5%	0.6%	1.6%	0.453	0.623	0.112
	NJ EiE	0.0%	98.3%	0.0%	1.7%	n/a		
Bird	control	0.0%	99.4%	0.3%	0.3%	1.000	0.613	0.461
	NJ EiE	0.0%	98.6%	0.7%	0.7%	1.000		

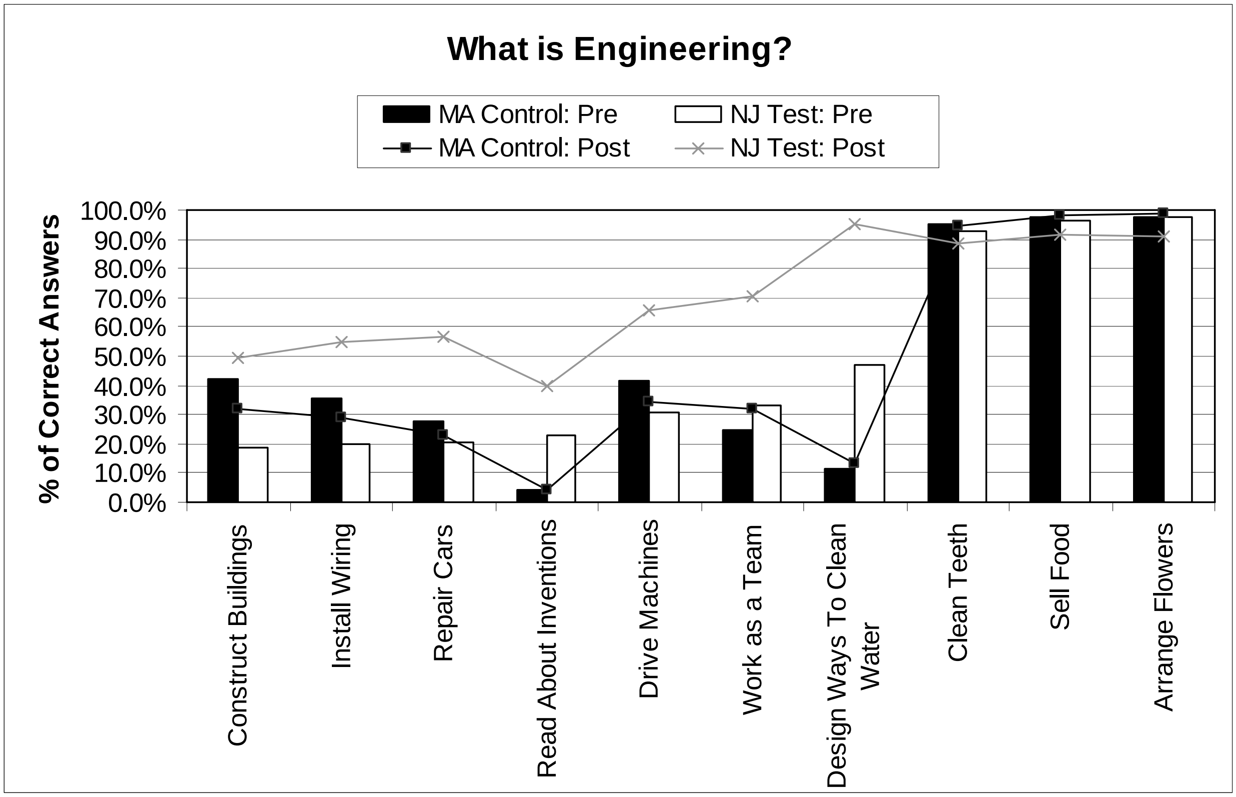
The easiest items for students to classify—Bird, Dandelion, Tree, Television, Power Lines, and Phone—all have either no significant differences or relatively low significant differences between Test & control and between Pre & Post. The nine more difficult items—which are clustered at the beginning of the chart—all show significant differences from Pre to Post for the New Jersey EiE students, and significant differences between the control and New Jersey EiE students on the post-assessments (right-most column). The significant differences are large ones: between 5-25% of the control students improved their scores; however a much larger percentage of the New Jersey EiE students, between 40-50%, did so on all items except Factory.

Additionally, the percentage of EiE NJ students who "Regressed" is consistently low—4.1% or less—while the percentage of control students who "Regressed" often approaches the number who "Improved"—up to 16.6%. This is especially true of the items toward the center of the table and chart—those which students show the most ambivalence about classifying as "technology" or "not technology". This shows that on the post-assessment the New Jersey EiE students consistently separated natural things from human-made things in choosing which things are technologies, while the control students continued to display uncertainty.

What is Engineering?

The differences Pre- to Post- for New Jersey EiE students are not as dramatic for the *What is Engineering?* items as for the *What is Technology?* items, but are still clear. Again, the graph shows that NJ EiE students outperformed control students on the post-assessments: while the black control post-assessment line closely hugs the black pre-assessment bars, the gray NJ EiE post-assessment line shows that considerably more EiE students think that engineers read about inventions, work as a team, and design ways to clean water after completing EiE units than beforehand. In addition, NJ EiE students are much less likely to think that engineers drive machines, repair cars, install wiring, or construct buildings after completing EiE units. Unfortunately they are also slightly more likely to think that engineers "do everything"—they are more likely to say that engineers arrange flowers, sell food, and clean teeth for their jobs as well. All of these patterns mirror patterns we see in the larger, national sample of EiE students.

Significant differences exist between the NJ EiE student response patterns and those of the control students on every question. For the three jobs least likely to be chosen by students as the kind of work that engineers do—Arrange Flowers, Sell Food, and Clean Teeth, NJ EiE students showed a slight but significant tendency to regress on the post-assessment (that is, to choose these as "engineering" jobs on the post-assessment when they had not chosen them on the pre-). control students showed no significant change on these three items. For Read About Inventions and Design Ways to Clean Water, control students showed no significant change from pre- to post-, but NJ EiE students were much more likely to choose these jobs as engineering (p=.000). NJ EiE students were also much more likely to say that engineers Work as a Team on the post-assessment (p=.000), but control students were also more likely to choose that item (p=.032). For the final four items—Drive Machines, Repair Cars, Install Wiring, and Construct Buildings—NJ EiE students were significantly more likely on the post-assessment to get them correct (by not choosing them as engineering work, p=.000) while control students were significantly **less** likely to answer them correctly (p= marked with an asterisk*).

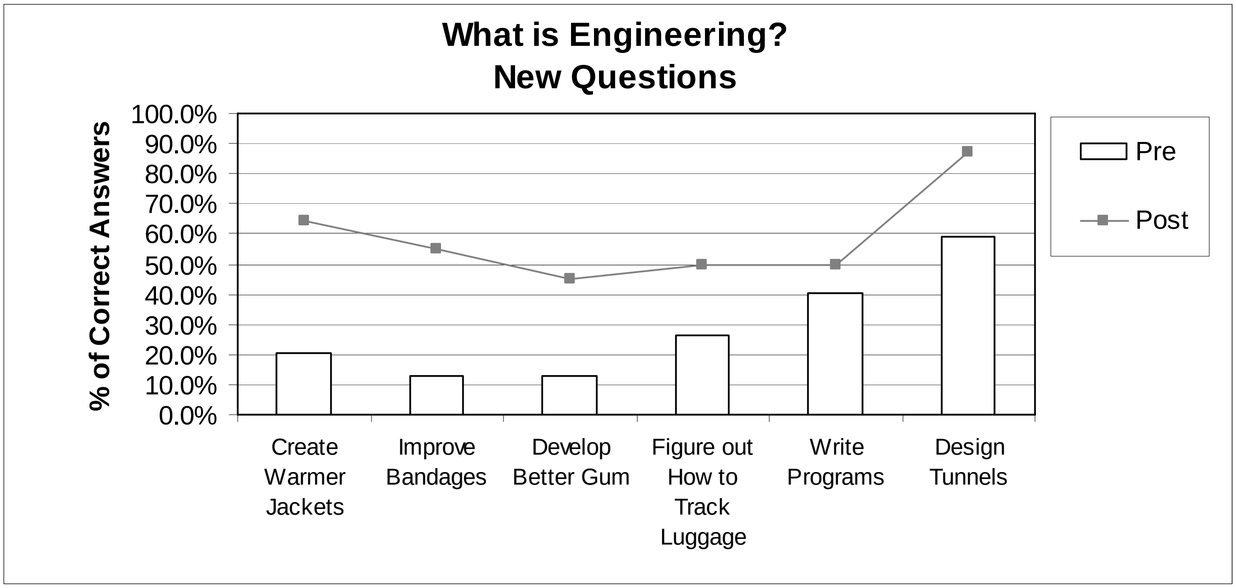


What is Engineering?		**Neither correct**	**Both correct**	**Regressed**	**Improved**	**Pre*Post Differences: McNemar p=**	**control * Test Differences:** Within Pre Phi p=	Within Post Phi p=
Read About Inventions	control	93.0%	0.5%	2.8%	3.6%	0.690	**0.000**	**0.000**
	NJ EiE	49.8%	13.3%	10.2%	26.6%	**0.000**		
Install Wiring	control	51.4%	15.7%	20.6%	12.3%	**0.006***	**0.000**	**0.000**
	NJ EiE	37.9%	12.6%	7.8%	41.6%	**0.000**		
Repair Cars	control	62.2%	12.3%	15.4%	10.0%	**0.044***	**0.019**	**0.000**
	NJ EiE	36.2%	13.3%	7.8%	42.7%	**0.000**		
Construct Buildings	control	45.0%	22.4%	21.1%	11.6%	**0.001***	**0.000**	**0.000**
	NJ EiE	45.2%	12.3%	5.5%	37.0%	**0.000**		
Drive Machines	control	44.8%	21.1%	21.4%	12.6%	**0.004***	**0.002**	**0.000**
	NJ EiE	25.7%	23.6%	8.6%	42.1%	**0.000**		
Design Ways To Clean Water	control	78.6%	3.4%	8.2%	9.8%	0.550	**0.000**	**0.000**
	NJ EiE	3.8%	46.4%	1.0%	48.8%	**0.000**		
Work As A Team	control	56.3%	13.7%	11.9%	18.1%	**0.032**	**0.010**	**0.000**
	NJ EiE	25.9%	30.0%	3.8%	40.3%	**0.000**		
Clean Teeth	control	1.0%	91.5%	4.1%	3.3%	0.711	0.143	**0.001**
	NJ EiE	1.7%	83.3%	10.2%	4.8%	**0.023***		
Sell Food	control	0.0%	96.1%	1.3%	2.6%	0.302	0.336	**0.000**
	NJ EiE	1.0%	88.7%	7.8%	2.4%	**0.005***		
Arrange Flowers	control	0.0%	96.9%	1.0%	2.1%	0.388	0.949	**0.000**
	NJ EiE	0.0%	88.1%	9.2%	2.7%	**0.002***		

* Significant regression from pre- to post-assessment.

Some questions in the *What is Engineering?* table were new to the assessments since control data was collected, so there is no control comparison. These questions are discussed in the following chart and table.

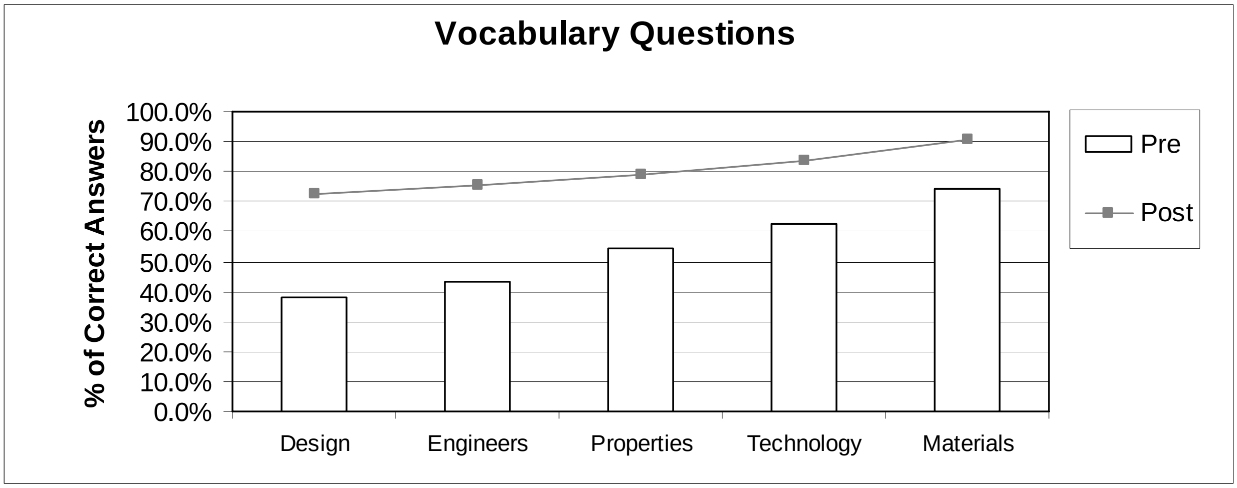
New Jersey EiE students were significantly more likely on the post-assessment than on the pre-assessment to say that engineers might Improve Bandages, Develop Better Gum, Figure out How to Track Luggage, Create Warmer Kinds of Jackets, Design Tunnels, and Write Computer Programs for their jobs. All differences but one (Write Computer Programs) were highly significant according to the McNemar Test of Symmetry (see the table and chart below).



What is Engineering?	Neither correct	Both correct	Regressed	Improved	McNemar Test of Symmetry p=
Develop Better Bubble Gum	51.9%	10.6%	2.4%	35.2%	**0.000**
Write Computer Programs	32.8%	25.6%	17.7%	23.9%	0.123
Figure Out How to Track Luggage	41.6%	18.8%	8.2%	31.4%	**0.000**
Improve Bandages	41.3%	11.3%	2.7%	44.7%	**0.000**
Create Warmer Kinds of Jackets	32.4%	16.7%	3.4%	47.4%	**0.000**
Design Tunnels	7.5%	55.3%	5.5%	31.7%	**0.000**

Vocabulary Questions

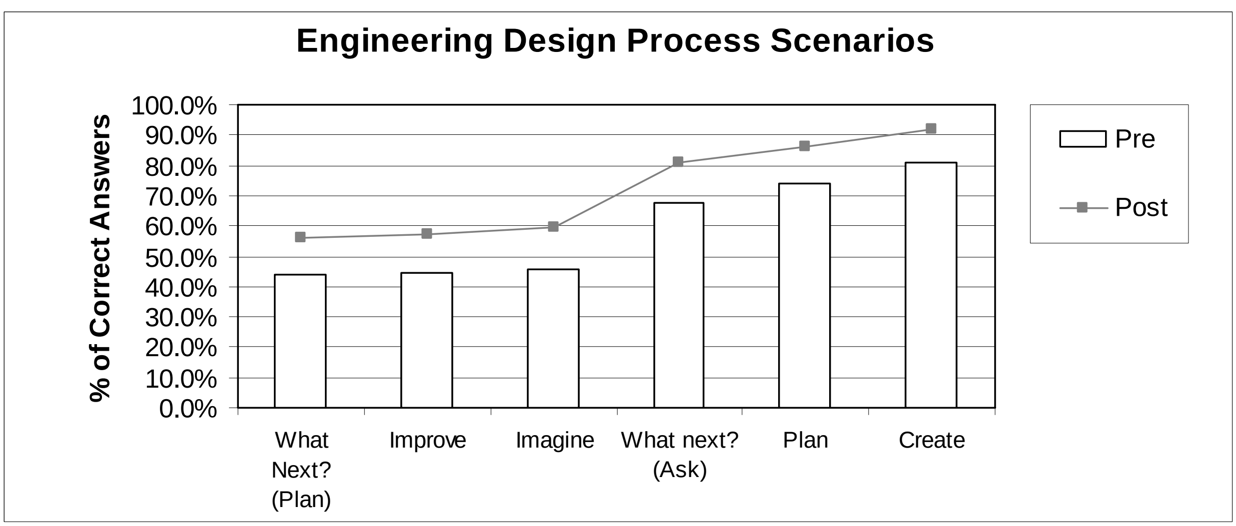
Students were asked to correctly complete sentences with engineering vocabulary words. For each sentence, they were given three words to choose from. New Jersey students participating in EiE were significantly more likely (p=.000) to choose the correct vocabulary word on the post-assessment than on the pre-assessment. 278 New Jersey students answered these questions. (control students did not receive these questions so there is no comparison available.)



Vocabulary Questions	Neither correct	Both correct	Regressed	Improved	McNemar Test of Symmetry p=
Properties	15.6%	49.5%	5.5%	29.5%	**0.000**
Materials	4.3%	71.9%	4.3%	19.4%	**0.000**
Technology	8.3%	55.4%	8.7%	27.5%	**0.000**
Design	19.8%	31.3%	8.6%	40.3%	**0.000**
Engineers	17.3%	35.0%	6.9%	40.8%	**0.000**

Questions about the Engineering Design Process

We asked the New Jersey 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. In two cases, the question asked which step would come next. On all questions, New Jersey EiE students were significantly more likely to choose the correct answers on the post-assessment than on the pre-assessment.



Engineering Design Process Questions	Neither correct	Both correct	Regressed	Improved	McNemar Test of Symmetry p=
What Next? (Plan)	23.2%	26.4%	20.1%	30.3%	**0.019**
Improve	29.3%	31.7%	13.4%	25.5%	**0.001**
Imagine	22.7%	31.5%	16.8%	29.0%	**0.003**
Ask	9.9%	60.2%	8.5%	21.5%	**0.000**
Plan	6.0%	68.7%	8.1%	17.3%	**0.003**
Create	3.1%	78.0%	4.5%	14.4%	**0.001**

A Question Asking about Materials

One more question was asked of students: "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?" 83.5% of New Jersey EiE students correctly identified the answer as "Material for the chair" on the pre-assessment. 90.5% correctly identified the answer on the post-assessment. This difference is significant (McNemar Test of Symmetry p=.036). However, because so many students answered it correctly on the pre-assessment, this question has been dropped from the new 2006-2007 assessments.

Gender Differences on General Engineering Questions

Gender differences were uncommon and tended to be small on all assessments. They were more common on the pre-assessments than on the post-assessments. Gender differences were most common on the *What is Technology?* Assessment, with 6 of 16 items on the pre-assessment showing gender differences and 3 of 16 items on the post-assessment showing gender differences. Males were more likely to correctly classify items as technology (or not) than females for all significant items except one: on the pre-assessment, females were significantly more likely to correctly identify a phone as technology.

What is Technology?	Pre		Phi	Post		Phi
Gender Differences	Female	Male	p=	Female	Male	p=
Cup	10.90%	17.70%	0.075	59.30%	63.40%	0.478
Bandage	14.40%	18.30%	0.329	63.30%	71.80%	0.121
Books	13.30%	24.40%	**0.009**	52.00%	61.30%	0.110
Shoes	17.20%	20.70%	0.413	62.00%	71.80%	0.075
House	25.90%	42.10%	**0.002**	66.70%	72.50%	0.276
Bicycle	24.70%	45.10%	**0.000**	69.30%	83.80%	**0.004**
Bridge	31.60%	43.30%	**0.026**	69.30%	79.60%	**0.045**
Factory	74.10%	78.70%	0.328	90.00%	89.40%	0.874
Lightning	75.90%	84.80%	**0.040**	91.30%	96.50%	0.068
Subway	92.00%	93.30%	0.638	97.30%	95.80%	0.464
Power Lines	94.20%	92.00%	0.426	97.30%	94.40%	0.202
Television	96.00%	95.70%	0.910	96.70%	97.20%	0.799
Phone	98.90%	95.10%	**0.043**	99.30%	98.60%	0.530
Tree	98.30%	97.60%	0.645	97.30%	100.00%	**0.050**
Dandelions	98.90%	97.60%	0.370	100.00%	100.00%	.(c)
Bird	99.40%	99.40%	0.967	98.70%	100.00%	0.167

One interesting trend to note, however, is that whether the differences were significant or not, more males than females tended to get the non-canonical examples of technology (and nature)—the more difficult items at the beginning of the chart—correct, while both females and males tended to do equally well on the easier, canonical items. In the chart above, the cells showing the larger percentage of correct answers—male or female—are shaded when the difference is larger than 3%, in order to illustrate this trend. This suggests that a slightly larger number of males than females had the broad understanding that technology is anything human-made—both on the pre-assessment and on the post-assessment.

On the *What is Engineering?* Assessment, only 2 items of 16 on the pre-assessment (Install Wiring and Repair Cars) and 2 items of 16 on the post-assessment (Install Wiring and Design Ways to Clean Water) showed significant gender differences. In all four cases, females were significantly more likely to answer correctly than males. There was no clear pattern of non-significant gender differences on the pre-assessment, but on the post-assessment at least 3% more females answered correctly than males on 7 of the 16 items.

What is Engineering?	**Pre**			**Post**		
Gender Differences	**Female**	**Male**	**Phi p=**	**Female**	**Male**	**Phi p=**
Read About Inventions	21.80%	25.20%	0.473	39.30%	40.80%	0.792
Install Wiring	24.70%	14.70%	**0.022**	60.70%	48.60%	**0.038**
Repair Cars	25.90%	14.10%	**0.007**	62.70%	50.70%	0.039
Construct Buildings	19.00%	17.90%	0.802	53.30%	46.50%	0.242
Drive Machines	29.90%	31.30%	0.780	68.00%	64.10%	0.480
Design Ways To Clean Water	47.10%	48.50%	0.806	98.00%	93.00%	**0.037**
Work As A Team	32.80%	33.70%	0.848	72.00%	69.00%	0.576
Clean Teeth	93.70%	91.40%	0.427	90.70%	85.20%	0.151
Sell Food	97.10%	95.10%	0.338	94.00%	88.00%	0.073
Arrange Flowers	97.70%	97.50%	0.926	92.00%	89.40%	0.450
Develop Better Bubble Gum	13.80%	12.90%	0.806	44.70%	46.50%	0.756
Write Computer Programs	39.10%	42.90%	0.471	48.00%	52.10%	0.482
Figure Out How to Track Luggage	25.30%	28.20%	0.543	52.00%	49.30%	0.644
Improve Bandages	13.20%	13.50%	0.940	54.00%	58.50%	0.444
Create Warmer Kinds of Jackets	19.00%	22.70%	0.398	64.00%	64.80%	0.888
Design Tunnels	62.10%	56.40%	0.293	86.00%	88.00%	0.607

There were no significant gender differences on any of the remaining General Engineering assessment questions.

From these results, the conclusion can be drawn that both males and females have interest and ability in learning about engineering and technology, as presented by the *Engineering is Elementary* curriculum. Though males are slightly more likely to come to the program already having a clear idea of what technology is, that slight advantage is very quickly eroded during the weeks spent on the curriculum units.

Results for the Designing Water Filters Unit Questions

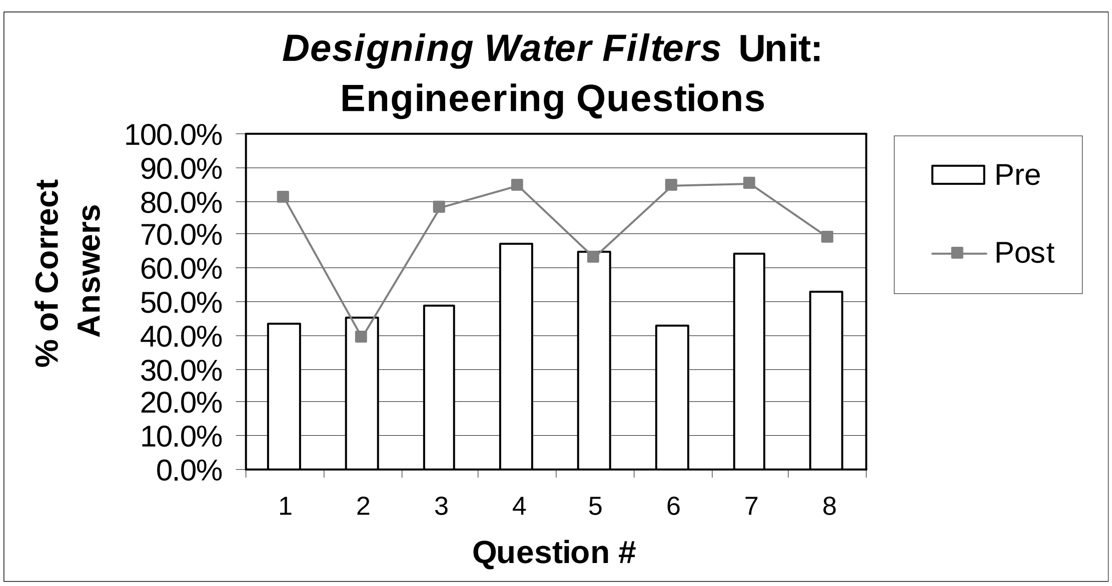
Designing Water Filters Unit: Question with control Comparison

Only one question on the Water Filters unit assessment was shared between the control sample and the New Jersey EiE sample. This question asked about condensation. New Jersey EiE students were significantly more likely to answer this question correctly on the post-assessment than on the pre-assessment; while the pre-post difference for control students was not significant. However, New Jersey students were significantly less likely to answer this question correctly than control students on the pre-assessment and also on the post-assessment, for unknown reasons.

Designing Water Filters **Unit: Condensation Question**		**Pre**	**Post**	**McNemar Test of Symmetry 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	81.0%	87.0%	0.728
	NJ Test	50.5%	71.7%	**0.000**
Phi Coefficient p=	Test * control	**0.000**	**0.000**	

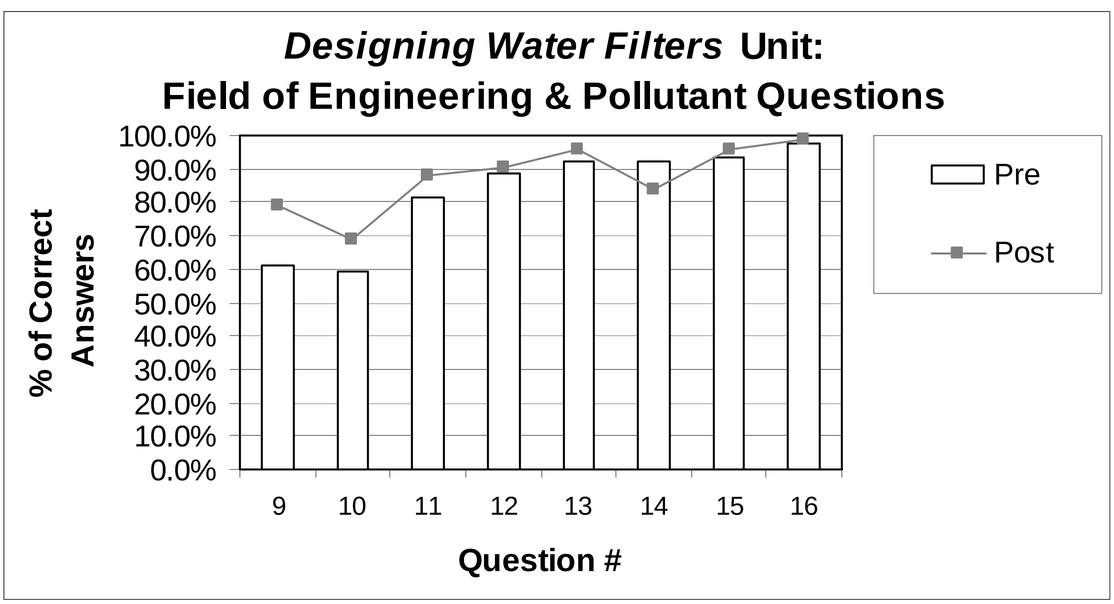
Designing Water Filters Unit Questions without control Comparison

New Jersey 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 when looked at in aggregate, 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 was Question #1 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).



Question #	***Designing Water Filters* Unit: Engineering Questions**	**Neither correct**	**Both correct**	**Regressed**	**Improved**	**McNemar Test of Symmetry p=**
1	What is NOT a way to make water cleaner?	16.1%	38.2%	4.2%	41.4%	**0.000**
2	Would SAND be a good material to filter leaves from water?	35.3%	19.6%	24.5%	20.6%	0.379
3	Would PAPER be a good material to filter leaves from water?	16.0%	40.4%	7.0%	36.6%	**0.000**
4	Would a SCREEN be a good material to filter leaves from water?	7.7%	58.7%	9.1%	24.5%	**0.000**
5	Would SAND be a good material to filter flour from water?	14.0%	42.0%	23.8%	20.3%	0.423
6	Would PAPER be a good material to filter flour from water?	7.3%	32.8%	8.0%	51.9%	**0.000**
7	Would a SCREEN be a good material to filter flour from water?	5.6%	54.4%	9.1%	31.0%	**0.000**
8	What material is best to use for a net to clean pool water?	20.0%	40.0%	9.7%	30.3%	**0.000**

New Jersey 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. Two of the four questions about engineering work showed significant improvement; the fourth showed a ceiling effect (about 90% correct both pre- and post-). Questions #13-16 about pollutants proved, for the most part, to be much too easy for students in grades 4-5, and have been omitted from future assessments. The only exception was Question #14 about the "dog", which we have decided 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.

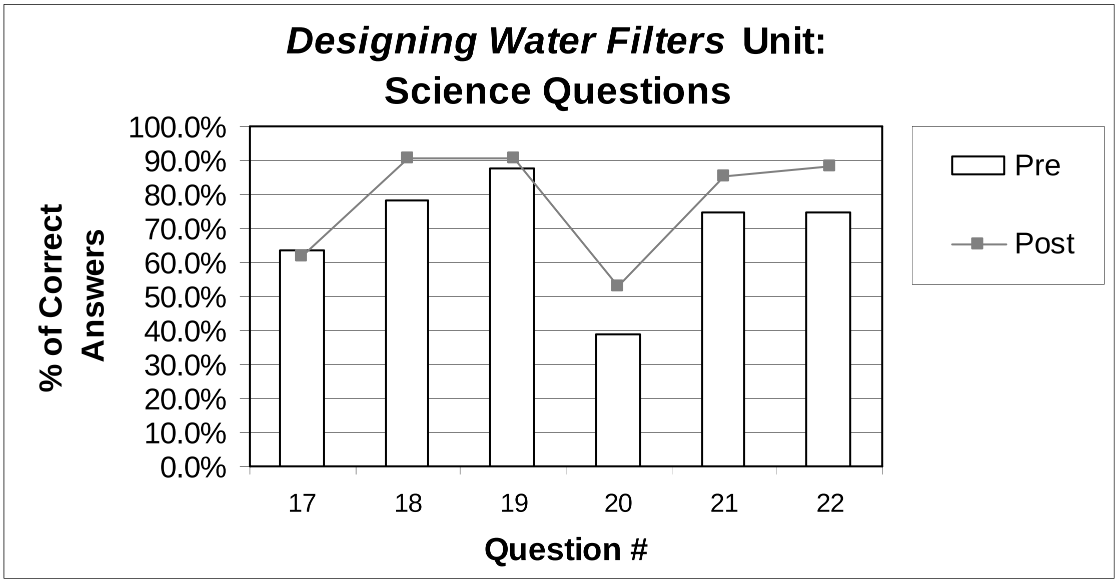


Question #	***Designing Water Filters*** **Unit: Field of Engineering and Pollutant Questions**	**Neither correct**	**Both correct**	**Regressed**	**Improved**	**McNemar Test of Symmetry p=**
9	For his job, an environmental engineer might stop harmful plants from growing in a lake.	10.7%	51.4%	10.0%	27.9%	**0.000**
10	For his job, an environmental engineer might rescue dolphins.	20.3%	47.4%	11.3%	21.0%	**0.005**
11	For his job, an environmental engineer might decide how to clean air.	5.2%	74.1%	7.9%	12.8%	0.092
12	For his job, an environmental engineer might sort river rocks.	2.4%	81.4%	7.6%	8.6%	0.771
13	A CAR could add pollutants to the air.	2.1%	90.7%	2.4%	4.8%	0.189
14	A DOG could add pollutants to the air.	4.8%	79.7%	12.7%	2.7%	**0.000***
15	A WATERFALL could add pollutants to the air.	1.7%	91.4%	3.1%	3.8%	0.824
16	A FACTORY could add pollutants to the air.	0.3%	96.9%	1.0%	1.7%	0.727

* This question was discarded as problematic.

Designing Water Filters Science Content Questions

The remaining six questions for the Water Filters unit are science content questions. New Jersey EiE students showed significant improvement on all but two of these questions. Of the two, question #19 appears to have been too easy for grades 4-5 (nearly 88% of students answered the pre-assessment correctly) and so is showing a ceiling effect. The other question showed a slight and not significant regression (fewer students answered correctly on the post-assessment): question #17. This is consistent with results we have seen in other populations (Massachusetts and nationally) and may reflect either a common misconception, or 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.



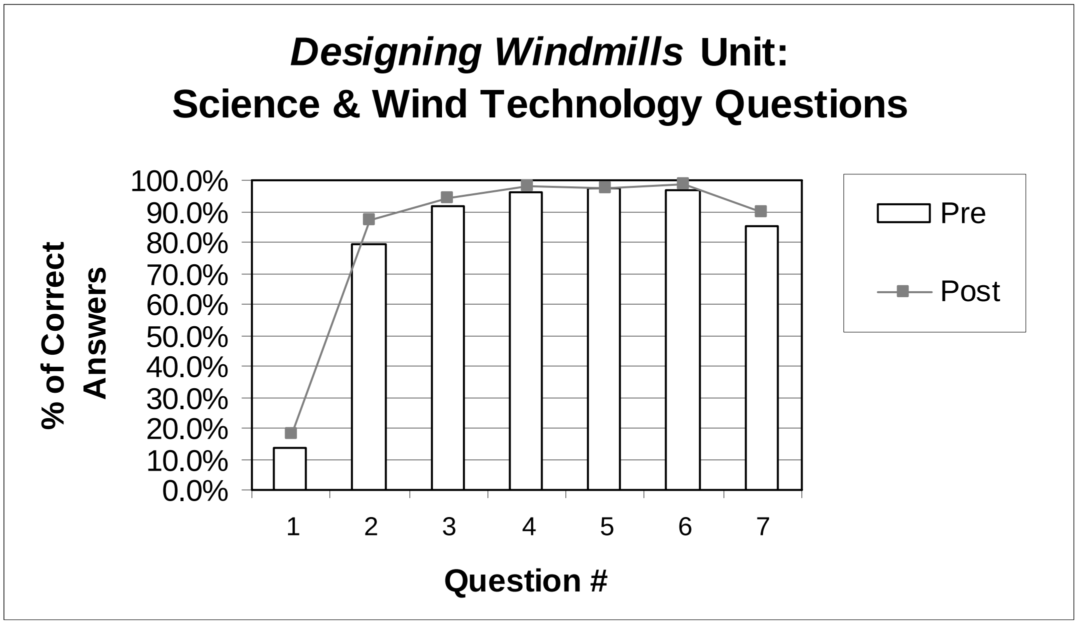
Question #	***Designing Water Filters* Unit: Science Questions**	**Neither correct**	**Both correct**	**Regressed**	**Improved**	**McNemar Test of Symmetry p=**
17	True or false: Earth has a limited amount of fresh water	23.0%	50.5%	15.0%	11.5%	0.302
18	True or false: Condensation is part of the water cycle	3.8%	73.4%	5.5%	17.3%	**0.000**
19	True or false: Water disappears forever when it evaporates	2.4%	82.7%	6.2%	8.7%	0.360
20	True or false: The water cycle makes new water	38.9%	29.2%	9.7%	22.2%	**0.000**
21	True or false: If polluted water freezes, it is no longer contaminated	7.3%	67.1%	7.6%	18.0%	**0.001**
22	True or false: Water can be a solid, liquid, or gas	7.3%	70.8%	2.8%	19.1%	**0.000**

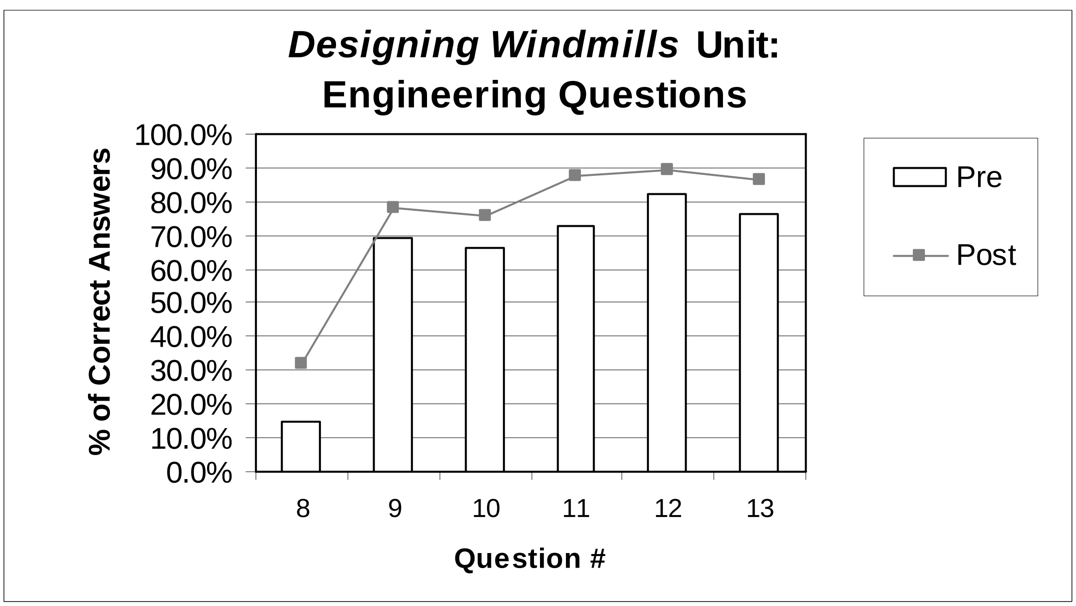
New Jersey EiE students demonstrated on the post-assessment for the *Designing Water Filters* unit that they learned a great deal about water, water filters, the materials used in water filtration, and the work done by environmental engineers over the course of this unit. Though it can be argued that learning about the properties of specific materials for water filtration is 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 learned what engineering and technology are, and the order and characteristics of the steps of the engineering design process.

The full text of the assessment for the Designing Water Filters unit can be found in Appendix B.

Results for the Designing Windmills Unit Questions

New Jersey students performed consistently better on the post-assessment than on the pre-assessment, but not all changes pre- to post- were significant. Question 1 appears to have been too difficult for students--only 13% answered correctly on the pre-assessment, and only 18% on the post-assessment. Questions 2 through 6 were too easy for students, with over 90% of students answering the pre-assessment correctly for four out of five items. For the remainder of the items—all of which were "engineering" content questions—New Jersey students showed significant improvement.





Question #	Windmills Unit Questions	Neither correct	Both correct	Regressed	Improved	McNemar Test of Symmetry p=
1	Which does NOT show how hard the wind is blowing?	76.3%	7.2%	6.5%	10.1%	0.184
2	GLIDER uses the energy of the wind	6.3%	73.1%	6.3%	14.3%	0.004
3	WEATHER VANE uses the energy of the wind	2.4%	89.2%	3.1%	5.2%	0.307
4	SAILING SHIP uses the energy of the wind	0.7%	95.1%	1.4%	2.8%	0.388
5	COMPUTER uses the energy of the wind	0.7%	95.1%	2.1%	2.1%	1.000
6	KITE uses the energy of the wind	0.3%	96.2%	1.0%	2.4%	0.344
7	ROCKET uses the energy of the wind	6.0%	81.8%	4.2%	8.1%	0.090
8	Improve windmill: Add more blades	62.0%	9.4%	5.9%	22.6%	0.000
9	Improve windmill: Put holes in the blades	13.9%	59.9%	9.1%	17.1%	0.011
10	Improve windmill: Change the material of blades	15.0%	57.1%	8.7%	19.2%	0.001
11	Improve windmill: Change the angle of blades	9.8%	70.3%	2.4%	17.5%	0.000
12	Windmills and sailboats:	7.9%	78.8%	3.2%	10.1%	0.003
13	For his job, mechanical engineer might:	8.3%	70.9%	5.3%	15.5%	0.000

These results demonstrate that students gained familiarity with materials and their uses in harnessing the power of the wind. They also learned more clearly the role of mechanical engineers in designing technologies. Again, this is only a smaller part of the big picture: that students learned through close experience with a few key examples more general lessons about the ubiquity and the diversity of technology and of engineering design.

The full text of the assessment for the Designing Windmills unit can be found in Appendix C.

Conclusions

New Jersey 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, NJ EiE students have, in almost every instance, performed significantly better than the control students. Specifically, NJ 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 materials and their uses in different situations for catching the power of the wind after completing the *Designing Windmills* unit.
- Are much more likely to correctly identify the work of mechanical engineers after completing the *Designing Windmills* unit.

An important goal of engineering education in the elementary grades is to introduce students to the most basic concepts of the applied sciences:

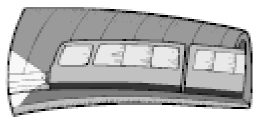
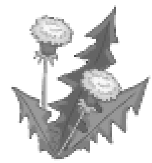
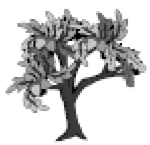
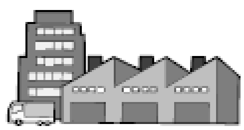
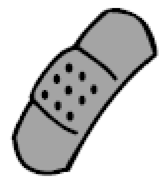
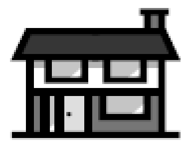
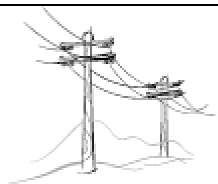
- Objects and processes in the world can be categorized as natural or as human-made.
- Human-made objects and processes can be described as technologies.
- The engineering design process is a principled process that is both different from and similar to the process of scientific discovery.
- Familiarity 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.

Appendix A: General Engineering Assessment

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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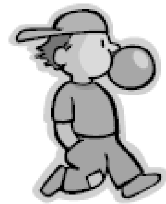
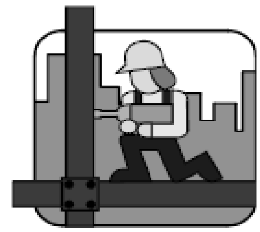
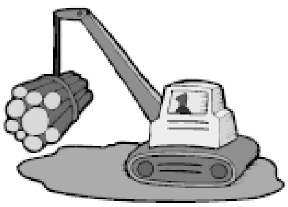
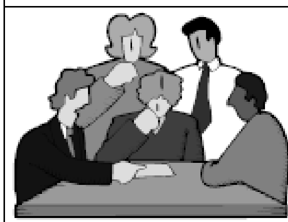
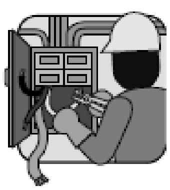
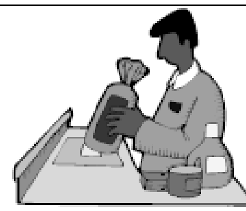
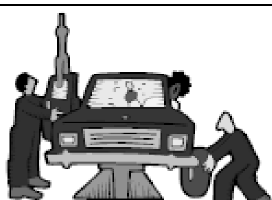
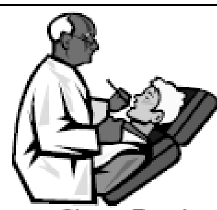
What is an Engineer?

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.

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.

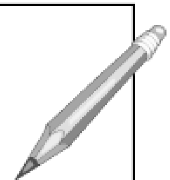
A. Ask

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

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

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?

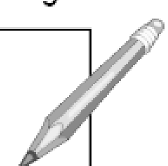
   A. Ask

   B. Imagine

   C. Plan

   D. Create

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



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

1. 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?

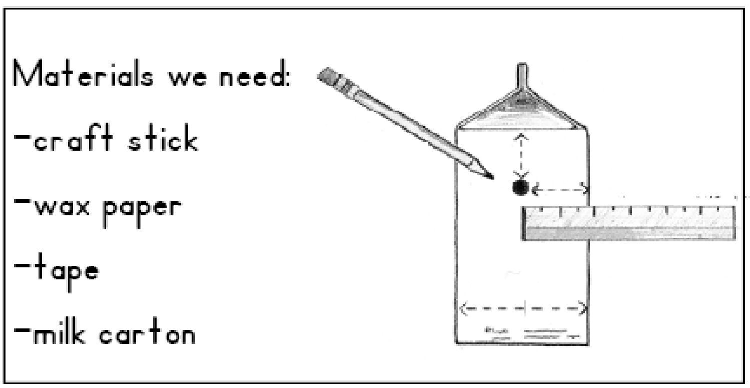
A. Properties of the chair

B. Material for the chair

C. Size of the chair

D. How the chair will be used

2. 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?



A. Ask

B. Imagine

C. Plan

D. Create

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

Appendix B: Designing Water Filters Unit Assessment

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?

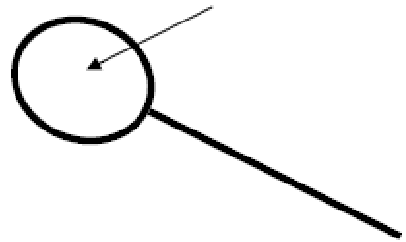
    A. It rained.

    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.

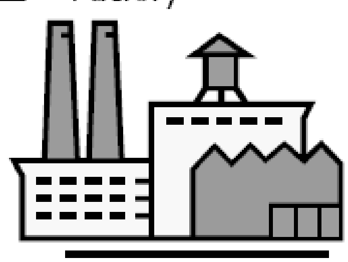
   ☐ Stop harmful plants from growing in a lake.

   ☐ 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 

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

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

Appendix C: Designing Windmills Unit Assessment

1. 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
   - ☐ Put holes in the blades to let air through
   - ☐ Change the material the blades are made of.
   - ☐ Change the angle of the blades.

2. Windmills and sailboats:

   A. make wind.
   B. use wind energy.
   C. use solar energy.
   D. don't need energy to move.

3. 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.

1. Which of the following does NOT show how hard the wind is blowing? Circle **ONE** answer.

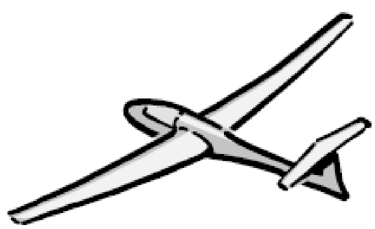
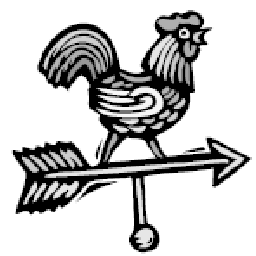
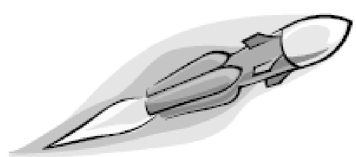
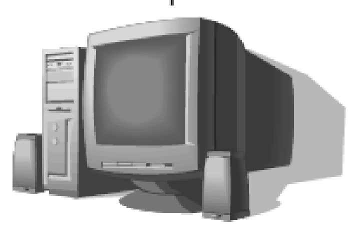
   A. a weather vane

   B. clouds

   C. an anemometer

   D. trees

2. Some technologies use the energy of the wind. Check **ALL** of the technologies that use the energy of the wind.

☐ Glider 	☐ Weather vane 
☐ Rocket 	☐ Computer 
☐ Kite 	☐ Sailing ship