# AC 2010-1411: TEACHING ENGINEERING ACROSS ELEMENTARY SCHOOLS

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# Teaching Engineering Across Elementary Schools


**Abstract:**

As part of a grant-funded three-year project, a cooperative effort took place to introduce *Engineering is Elementary* (EiE) into the elementary schools of four public school systems. Twenty-two teachers, one from each elementary school in the four school districts, were designated as lead teachers by the school systems and trained in teaching EiE. The teachers were supported by staff and professors of engineering, technology, mathematics, and science from two community colleges.

This paper describes the year-long process to introduce a unit of EiE into the classrooms of each of the twenty-two elementary school teachers, in such a way that each selected unit meshed with the unique curriculum of each elementary school.

The paper also describes the work done implementing surveys of student attitudes and implementing pre- and post-tests of student learning about engineers, the engineering design process and a unit of EiE.

Each school district also developed and began to implement appropriate plans for the professional development of additional elementary school teachers in EiE. A three-year goal of implementing a unit of EiE in two-thirds of the classrooms of each of the twenty-two elementary schools was established.

Included in the paper will be the findings of an outside evaluator hired to gather and evaluate data from the students and report the results.

The paper will conclude with lessons learned that will be applied in the second year expansion of the program which will include many more elementary school teachers implementing EiE within the four school systems.


## Introduction

In the spring of 2008, a grant-funded three-year project entitled THE PROJECT began. THE PROJECT sought to win hearts and minds of students in the elementary schools and to put the "T" and "E" (technology and engineering) back into STEM while emphasizing the supporting science and mathematics.

A major part of THE PROJECT was a cooperative effort to introduce *Engineering is Elementary* (EiE) into the elementary schools of four public school systems. In the spring of 2008, twenty-two teachers, one from each elementary school in four school districts (District A, District B, District C, and District D), were designated as lead teachers by the school systems. During the summer of 2008, the lead teachers were trained in teaching EiE. The teachers were supported by professors of engineering, technology, mathematics, and science from two community colleges. During the 2008-2009 school year, each lead teacher introduced one unit of Engineering is Elementary into his/her classroom.

The original aim of THE PROJECT was to introduce EiE into every classroom of all three grades (3, 4, and 5) of each elementary school. The reduced funding in the awarded grant required narrowing the scope of THE PROJECT to introducing EiE into every classroom of two grades of each elementary school in District A, District B, District C, and District D. Each of these school districts is the comprehensive public school system for a single city or town, and all are located within two adjacent counties of the same state.

**The Four Communities**

City A is a small city adjacent to the largest Hispanic city in the state. It has the largest population of the four communities and a significant non-white population. City A has the lowest median income of the four communities and is just below the state median income.

Towns B and C are adjacent suburban communities within the same county as Town D. Town D is another suburban town, older and smaller than Towns B and C, but it has the highest median income of the four communities. Towns B, C, and D are all well above the state median income.

**Table I: Population and Income Data by City/Town[1]**

| | Population July 2008 | Population Change since 2000 | Median Resident's Age | State Median Age | Median Income | State Median Income |
|---|---|---|---|---|---|---|
| **City A** | **44,055** | **+ 0.6%** | **37.5** | 36.5 | **$63,085** | $65,401 |
| **Town B** | **41,844** | **+ 7.3%** | **35.9** | 36.5 | **$87,174** | $65,401 |
| **Town C** | **34,409** | **+ 1.6%** | **38.9** | 36.5 | **$90,270** | $65,401 |
| **Town D** | **23,774** | **+ 0.3%** | **39.1** | 36.5 | **$99,080** | $65,401 |

**Table II: Population by Race/Ethnicity[2]**

| Races in the community | City A | Town B | Town C | Town D |
|---|---|---|---|---|
| White | 85.8 | 93.6 | 92.4 | 95.8 |
| Hispanic | 9.6 | 1.5 | 1.2 | 0.8 |
| Other Race | 4.9 | | 0.5 | |
| Two or More Races | 1.8 | 1.0 | 0.9 | 0.7 |
| Black | 1.3 | 1.1 | 0.8 | |
| Vietnamese | 0.6 | | | 0.5 |
| Asian Indian | 0.6 | 1.1 | 1.4 | 0.9 |
| Chinese | | 0.7 | 2.0 | |

**The Four School Districts**

District A, the school system of City A, has an even higher percentage of non-white students than the general population of City A as is shown in Table III and almost one-quarter of the students in District A are Hispanic.

**Table III: School Enrollment by Race/Ethnicity[3]**

| Enrollment by Race/Ethnicity (2008-09) | | | | | |
|---|---|---|---|---|---|
| **Race** | **% of District A** | **% of District B** | **% of District C** | **% of District D** | **% of State** |
| **African American** | **2.2** | **1.5** | **2.5** | **1.8** | **8.2** |
| **Asian** | **2.7** | **3.2** | **8.7** | **3.8** | **5.1** |
| **Hispanic** | **23.8** | **2.1** | **2.4** | **1.3** | **14.3** |
| **Native American** | **0.4** | **0.1** | **0.2** | **0.2** | **0.3** |
| **White** | **69.4** | **91.4** | **85.1** | **91.8** | **69.9** |
| **Native Hawaiian, Pacific Islander** | **0.0** | **0.1** | **0.0** | **0.1** | **0.1** |
| **Multi-Race, Non-Hispanic** | **1.4** | **1.6** | **1.2** | **1.1** | **2.0** |

Table IV shows that the school population by grade tracks the total population of each community with District A the largest and District D the smallest.

**Table IV: School Enrollment by Grade for Each District[4]**

| Enrollment by Grade (2008-09) | | | | |
|---|---|---|---|---|
| | **District A** | **District B** | **District C** | **District D** |
| **Grade 3** | **578** | **504** | **441** | **318** |
| **Grade 4** | **571** | **536** | **438** | **393** |
| **Grade 5** | **608** | **518** | **445** | **342** |

Table V shows that in looking at the performance of students in the four districts on the state-mandated tests of student achievement, District A scores appear significantly below the state-wide scores. Scores from Districts B and C appear to be roughly equal to the state-wide scores and District D appears significantly above the average. It should be noted that except for District B Science and Technology scores, District A is the only district where the majority of its students have test performance levels of "Needs Improvement" and "Warning/Failing." The tests of student achievement were administered before most of the lead teachers were able to introduce their units of EiE in the classroom in late spring of 2009. The earliest the positive effects of exposure to EiE can be measured by means of the state-wide tests of student achievement will be spring of 2010.

**Table V: Percent of Students at Each Performance Level as of May, 2009[5]**

| Grade and Subject | Advanced/ Above Proficient | | Proficient | | Needs Improvement | | Warning/ Failing | | Students Included |
|---|---|---|---|---|---|---|---|---|---|
| | District | State | District | State | District | State | District | State | |
| **District A GR 5 - Mathematics** | **9** | 22 | **32** | 32 | **34** | 29 | **25** | 18 | **611** |
| **District A GR 5 - Science and Technology** | **4** | 17 | **22** | 32 | **55** | 39 | **18** | 12 | **611** |
| **District B GR 5 - Mathematics** | **22** | 22 | **33** | 32 | **30** | 29 | **15** | 18 | **520** |
| **District B GR 5 - Science and Technology** | **14** | 17 | **30** | 32 | **47** | 39 | **9** | 12 | **517** |
| **District C GR 5 - Mathematics** | **22** | 22 | **38** | 32 | **31** | 29 | **9** | 18 | **456** |
| **District C GR 5 - Science and Technology** | **19** | 17 | **43** | 32 | **32** | 39 | **6** | 12 | **456** |
| **District D GR 5 - Mathematics** | **32** | 22 | **42** | 32 | **20** | 29 | **7** | 18 | **349** |
| **District D GR 5 - Science and Technology** | **23** | 17 | **40** | 32 | **33** | 39 | **4** | 12 | **349** |

**Project Description**

EiE is meant to be integrated with a school's existing science and mathematics curriculum. For example, simple machine concepts such as levers, inclined planes and pulleys, are traditionally introduced in the 4th or 5th grade of elementary school. These concepts would still be covered in science class but enhanced through the implementation of the "Marvelous Machines" unit of EiE. Table VI shows that District B chose to implement "Marvelous Machines" in Grade 5, but Districts C and D implemented "Marvelous Machines" in Grade 4 because simple machine concepts are covered in Grade 5 of District B, but in Grade 4 of Districts C and D. Likewise the EiE unit "An Alarming Idea" is implemented in Grade 4 of District B but in Grade 5 of District

C because electricity is part of the Grade 4 science curriculum of District B, but is not covered until Grade 5 in the science curriculum of District C.

The EiE unit selected by a teacher's school district allows the teacher to introduce the science topics and then use the engineering design process in conjunction with those science topics to design technical solutions to realistic problems. Teachers can reinforce science concepts by showing where the concepts are used. The different science curriculums used in the four elementary school systems of THE PROJECT often cover the same science topic in different grades which explains why the same unit of EiE may be used in different grade levels in each of the four school systems. Table VI shows that the EiE unit "Catching the Wind" is used in grade 4 of District A, but in Grade 3 of District D because the science topic Wind and Weather is covered in the Grade 4 science curriculum of District A but Wind and Weather is introduced in Grade 3 of District D.

The Teacher's Guide for each unit of EiE contains specific tie-ins with the science concepts of elementary school science curricula such as GEMS, FOSS, and STC as well as a mapping to the state Science and Technology/Engineering Standards (see appendix).

The units of EiE selected as most appropriate to each school district's science curriculum, the grade in which the unit will be used and the field of engineering on which the unit focuses are shown in Table VI. Each unit of EiE is also adjustable to different ability levels within a grade or a classroom.

**Table VI: Units of Engineering is Elementary by School System**

| District | Grade | Engineering is Elementary Unit Title | Engineering Field |
|---|---|---|---|
| District A | 3 | The Best of Bugs: Designing Hand Pollinators | Agricultural |
| District A | 4 | Catching the Wind: Designing Windmills | Mechanical |
| District B | 4 | An Alarming Idea: Designing Alarm Circuits | Electrical |
| District B | 5 | Marvelous Machines: Making Work Easier | Industrial |
| District C | 4 | Marvelous Machines: Making Work Easier | Industrial |
| District C | 5 | An Alarming Idea: Designing Alarm Circuits | Electrical |
| District D | 3 | Catching the Wind: Designing Windmills | Mechanical |
| District D | 4 | Marvelous Machines: Making Work Easier | Industrial |

**Activities to Achieve Objectives and Timeline**

From April, 2008 - June, 2008, District A, District B, District C, and District D public schools identified a total of twenty-two lead teachers, (one teacher from each elementary school in the four districts), who would become future trainers for EiE. Each of the four school systems selected two units of EiE which best fit the curriculum of that school system and the two grades out of the three grades, 3, 4, or 5, in which the units would be used. At the same time each of the two cooperating community colleges selected faculty to participate. One community college selected one engineering professor, one information technology professor, and three math professors. The other community college selected two engineering professors who also taught college mathematics and a math professor who held a master's degree in engineering.

From June 30 to July 2, 2008, the twenty-two teachers and eight community college faculty attended a three-day Teacher Educator Institute on Engineering is Elementary at the Museum of Science. The workshop introduced the participants to the nature of engineering and technology, the engineering design process and the interrelationship between science, engineering, technology, and mathematics. Within the workshop were two strands, each focusing on three different units of EiE. Each of the twenty-two teachers participated in the strand which contained the unit he/she would be implementing in his or her classroom in the spring of 2009.

The workshop began with a common first day that introduced the teachers to engineering, technology and the engineering design process with hands-on activities the teachers would later use in their own classrooms. Likewise the activities of each strand engaged the participants in activities their students would eventually experience. The teachers participated in the engineering design process using real EiE materials and student hand-outs and experienced for themselves the excitement of creating engineering solutions to real problems.

Participants also received an overview of the curriculum design of EiE. Each unit of EiE contains a preparatory lesson to prompt students to think about engineering, technology, and the engineering design process. Each unit contains four additional lessons: an illustrated story set in a particular locale that presents a problem facing a young person; a broad view of a particular engineering field personified by an engineer in the young person's life who helps the young person design a solution to the problem; the collection of data related to the problem and the application of scientific and mathematical analysis to the data; and a final engineering design challenge where students use the engineering design process to develop, create, and improve solutions to a problem similar to that faced by the young person in the story.

Table VII shows the units of EiE used in this project and the science topics, engineering field, storybook and setting related to each unit.

**Table VII: Units of EiE Related to Science and Engineering Fields**

| EiE Unit Title | Science Topic | Engineering Field | Storybook (Setting) |
|---|---|---|---|
| Catching the Wind: Designing Windmills | Wind & Weather | Mechanical | Leif Catches the Wind (Denmark) |
| Marvelous Machines: Making Work Easier | Simple Machines | Industrial | Aisha Makes Work Easier (USA) |
| The Best of Bugs: Designing Hand Pollinators | Insects/Plants | Agricultural | Mariana Becomes a Butterfly (Dominican Republic) |
| An Alarming Idea: Designing Alarm Circuits | Electricity | Electrical | A Reminder for Emily (Australia) |

Later in the summer, four day-long planning sessions were held, one for each of the four school systems. At these planning sessions the lead teachers and the community college faculty discussed the science and math topics associated with particular units of EiE and ascertained what additional help they would need to successfully implement the units. They also estimated the number of story books, kits and refills needed for each school system.

The lead teachers from each school system developed lesson plans for each class session detailing how they would teach the chosen unit of EiE in the classroom and when it would be taught during 2008-2009. The preliminary estimate was that the unit of EiE might be taught according to the following schedule, Table VIII.

**Table VIII: Proposed Schedule for Teaching EiE in the Schools**

| District | Grade | EiE Unit Title | Sessions | Earliest Start Date |
|---|---|---|---|---|
| District B | 4 | An Alarming Idea: Designing Alarm Circuits | 15 | January 5 |
| District B | 5 | Marvelous Machines: Making Work Easier | 14 | November 15 |
| District C | 4 | Marvelous Machines: Making Work Easier | 9 | December 15 |
| District C | 5 | An Alarming Idea: Designing Alarm Circuits | 15 | January 5 |
| District A | 3 | The Best of Bugs: Designing Hand Pollinators | 7 | November 15 |
| District A | 4 | Catching the Wind: Designing Windmills | 7 | November 15 |
| District D | 3 | Catching the Wind: Designing Windmills | 9 | February 15 |
| District D | 4 | Marvelous Machines: Making Work Easier | 9 | February 15 |

This proposed schedule proved to be overly optimistic for all four districts; but delays were accommodated and the teaching of the units was completed by June, 2009.

In addition, at the four day-long planning sessions during the summer of 2008, the lead teachers and community college faculty developed plans for the professional development, over the next two school years, of an additional one hundred eighty-four elementary school teachers. These professional development plans were presented to the administrations of the four school systems at the end of the summer. When the original proposal was written, the four school systems had agreed to provide eight hours of professional development time during the school year for the rest of their elementary school teachers. During the implementation of the grant, each school district has continued to honor that agreement.

During the late summer and fall of 2008, grant funds were used to purchase the storybooks, Teacher's Guides, and some of the kits of materials from the Museum of Science. When it was learned that not all of the needed kits would be available until February, 2009, instructional materials were purchased directly from suppliers and additional kits were assembled. During the fall of 2008, the lead teachers of each school system prepared to introduce the selected units of EiE into their classrooms.

Two of four districts decided to have an initial professional development session in the fall of 2008 to introduce the philosophy and curriculum of EiE to all of the elementary school teachers. All four districts decided to do the bulk of their professional development for the rest of their teachers after the lead teachers had taught their units in the classroom. This scheduling meant that for three of the districts professional development activities would not begin until the fall of 2009.

Beginning with the fall of 2009, another one hundred eighty-four teachers from grades three to five in the four school districts began professional development in EiE. They were supported by the lead teachers and the community college faculty as they prepared to integrate a unit of EiE into their classrooms over the next two academic years: 2009-2010 and 2010-2011.

**Description of the Participating Lead Teachers**

Before starting the Teacher Educator Institute, each of the lead teachers filled out a participant survey. Tables IX and X tabulate the participant survey responses and reflect the number of years the teachers have been employed in education and their educational backgrounds.

**Table IX: Number of Years Employed in Education**

| Years in Education | 3 | 3.5 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 13 | 16 | 17 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Teachers | 3 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table X: Educational Background of the Lead Teachers**

| | **Subject** | **Bachelor's Degree** | **Master's Degree** | **Doctorate** |
|---|---|---|---|---|
| **Degrees currently held** | Art | 1 | | |
| | Education | 3 | 16 | |
| | English Language | 3 | | |
| | History/Political | 2 | | |
| | Science | 1 | | |
| | Special Education | 1 | | |
| | Health | 1 | | |
| | Nursing | 1 | | |
| | Other | 4 | | |
| **Degrees currently being pursued** | **Subject** | **Bachelor's Degree** | **Master's Degree** | **Doctorate** |
| | Education | | 5 | |
| | Mathematics | | 1 | |
| | Other | 1 | 1 | |

The majority of the lead teachers have less than 10 years' experience. Also, all the lead teachers have or are pursuing a master's degree. However, because the majority of the advanced degrees are in education, THE PROJECT initiative is very important since it engages teachers in STEM ideas and concepts that they would not have been exposed to in their pursuit of advanced degrees in education.

Table XI displays data taken from a web site for all of the teachers in each of the four school systems. The fractional numbers for the total number of teachers are caused by including part-time teachers as fractions.

**Table XI: Teacher Data 2008-2009 for All Teachers in Each District[6]**

| | District A | District B | District C | District D | State |
|---|---|---|---|---|---|
| Total # of Teachers | 502.8 | 434.5 | 350.3 | 302.8 | 70,395.9 |
| % of Teachers Licensed in Teaching Assignment | 97.4 | 96.5 | 99.4 | 98.7 | 96.6 |
| Total # of Classes in Core Academic Areas | 2,123 | 1,474 | 1,459 | 1,099 | 279,742 |
| % of Core Academic Classes Taught by Teachers Who are Highly Qualified | 96.8 | 95.3 | 99.4 | 99.1 | 96.5 |
| Student/Teacher Ratio | 14.7 to 1 | 14.0 to 1 | 15.8 to 1 | 14.6 to 1 | 13.6 to 1 |

**Project Activities - January through June 2009**

Each of the lead teachers introduced a unit of EiE into their classrooms between February and June of 2009. Twelve of the lead teachers had their students participate in at least one of the four assessment tools: an on-line pre-survey of student attitudes toward STEM learning, an on-line post-survey of student attitudes toward STEM learning, a paper-and-pencil pre-test of content knowledge, or a paper-and-pencil post-test of content knowledge. The instrument used as a pre-survey and a post-survey of attitudes toward STEM learning was provided by the evaluator. "This instrument was devised at XXXX University and has gone through extensive validation studies drawing upon large-scale projects from multiple settings. The twenty-item assessment covers four domains: school, academics, the occupation of engineering, and the students' aspirations to becoming an engineer." [7] Only three lead teachers, two from District C and one from District A, were able to have their students complete all four of the assessment tools. Table XII provides the details.

**Table XII: Survey and Assessment Overview - Spring 2009**

| Teacher | District | School | Content Pre-Test Average Score | Content Post-Test Average Score | # of responses to Attitude Pre-survey | # of responses to Attitude Post-surveys |
|---|---|---|---|---|---|---|
| H | District C | SR | 8.70 | 9.85 | 25 | 24 |
| S | District C | PMS | 5.52 | 6.76 | 48 | 45 |
| T | District A | CGS | yes* | yes* | 19 | 21 |
| K | District C | MMS | 6.33 | 6.64 | | |
| L | District D | AMB | 10.45 | 9.85 | | |
| K | District D | WE | 9.05 | 10.89 | | 20 |
| C | District B | AJD | 7.28 | 10.36 | | 2 |
| B | District A | CGS | | | | 21 |
| M | District A | M | | | | 22 |
| LG | District B | K | | | | 22 |
| O | District B | V | | | | 16 |
| C | District C | H | | | | 25 |

* Data not submitted

Three of the lead teachers shown in Table XII (Teacher C of District B, Teacher O of District B, and Teacher C of District C) were able to complete the teaching of their unit of EiE by the end of March, 2009 and have their students complete the on-line post-survey of student attitudes toward STEM, engineers, and engineering.

**Project Evaluation Activities - January, 2009 through March, 2009**

The post-EiE survey results for these students submitting surveys in March 2009 (that is, the sixteen students of Teacher O of District B and the twenty-two students of Teacher M of District A) were combined with survey results for two other groups of students who experienced similar programs in two other towns and a report on the results of administering the survey to the four groups of students was completed by an outside evaluator in April 2009. That document, entitled **Annual Evaluation Report**[8], states that although the student attitudes were only measured with a post-survey, data based on a 4-point Likert scale were stronger on general performance categories and lower on engineering career-related items.

**Table XIII: Student Survey Results - April 2009**

| Item | Mean | Std. Deviation |
|---|---|---|
| The teachers at my school want me to do well in my schoolwork. | 3.46 | 0.79 |
| Being a student at my school is important to me. | 3.42 | 0.84 |
| I like being a student at my school. | 3.41 | 0.92 |
| There is more than one type of engineer. | 3.27 | 0.88 |
| I use computers as well as my classmates. | 3.20 | 0.79 |
| Engineers use science. | 3.20 | 0.92 |
| I am good at solving problems in mathematics. | 3.18 | 0.64 |
| Engineers work in teams. | 3.17 | 0.86 |
| I do my school work as well as my classmates. | 3.14 | 0.68 |
| I am good at working with others in small groups. | 3.14 | 0.88 |
| I make friends easy at my school. | 3.14 | 0.83 |
| Engineers solve problems that help people. | 3.13 | 0.86 |
| Engineers are creative. | 3.11 | 0.99 |
| Engineers use mathematics. | 3.06 | 1.11 |
| When I grow up I want to design different things. | 3.06 | 0.97 |
| When I grow up I want to solve problems that help people. | 2.93 | 0.92 |
| I am good at solving problems in science. | 2.90 | 0.90 |
| Engineers design everything around us. | 2.58 | 0.95 |
| When I grow up I want to work on a team with engineers. | 1.89 | 0.90 |
| When I grow up I want to be an engineer. | 1.82 | 0.95 |

XXRA compared the survey's total scores by group and district and no significant response differences emerged as shown in Table XIV. In another measure of homogeneity of student responses, XXRA found the Levene Statistic to be not significant in responses from the participating towns as indicated in Table XV.

**Table XIV: Survey Compared by District**

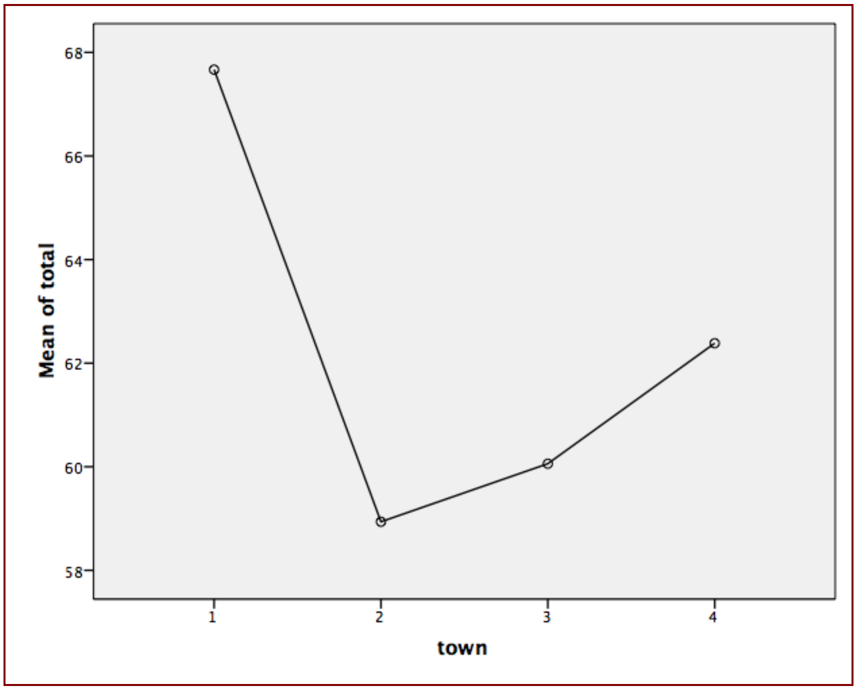
| Total Score | F | Sig. |
|---|---|---|
| Between Groups | 1.203 | .310 |

**Table XV: Survey Responses Variance**

| Levene Statistic | Sig. |
|---|---|
| .744 | .481 |

Looking at the variation among the programs in the towns, the summed responses from Town 1 students surpassed those from Town 2 students with Towns 3 and 4 falling in between Towns 1 and 2. This is shown graphically in Table XVI. The reporting schools from Town 1 and Town 2 were hosting after-school programs for middle school girls, whereas the schools from Towns 3 and 4, as participants in THE PROJECT, were using EiE units in the fourth grade of elementary school.

**Table XVI: Survey Responses by School**




## Project Evaluation Activities - April through June 2009

Table XII also shows that other students from two schools in District C and one school in District A completed both the pre-survey and the post-survey. This pre- and post- survey data was collected on-line between April and June 2009, downloaded to the evaluator's servers for cleaning, and then exported for analysis in SPSS.

In an **Interim Report** on the changes measured on the pre- and post- survey of attitude which is dated November 13, 2009, the evaluator wrote as part of the Executive Summary:

> Key findings include:
>
> - Students reported significant overall gains on the attitude assessment

- Effect sizes were quite small
- One of the three participating schools significantly outperformed the other two[9]

The sample for this report included 72 elementary and middle school students from the three schools for whom complete pre-post data had been recorded. About 100 other students from other schools had also participated; however the evaluator was not able to access both the pre- and post- data for them. The three schools are referred to in the **Interim Report** as School 2 (instead of CGS of District A), School 5 (instead of PMS of District C), and School 8 (instead of SR of District C).

The evaluator, in the body of the report, described the data gathering methodology, the four domains assessed, and the analysis of the assessment data and framed the central question for the evaluation research:

- To what extent were students' attitudes toward engineering changed as a consequence of participation in the project?

The evaluator's findings are shown in the following tables. Table XVII provides the statistics for the four domains and the overall scores.

**Table XVII: Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Effect Size |
|---|---|---|---|---|---|
| Pair 1 | Academics: Pre | 16.75 | 72 | 1.79 | .04 |
| | Academics: Post | 17.10 | 72 | 1.73 | |
| Pair 2 | School: Pre | 14.57 | 72 | 1.07 | .02 |
| | School: Post | 14.36 | 72 | 1.67 | |
| Pair 3 | Engineers: Pre | 23.25 | 69 | 2.90 | .13 |
| | Engineers: Post | 24.62* | 69 | 2.77 | |
| Pair 4 | Aspirations: Pre | 10.20 | 70 | 2.49 | .01 |
| | Aspirations: Post | 10.17 | 70 | 2.96 | |
| Pair 5 | Total: Pre | 64.73 | 67 | 5.94 | .08 |
| | Total: Post | 66.37* | 67 | 6.52 | |

*Significant at $p<.05$ (paired samples t-test)

Significant student gains in the awareness of the occupation of Engineering were achieved, though not evenly distributed. Interestingly, the pre-test scores were significant predictors of post-test scores and overall gain.

Table XVIII reveals that School 2 had significantly higher overall gains than the other two schools. School 2 is located in District A which was shown in Table I to have the lowest median income of the four districts in this project. Table III showed that District A also had the largest percentage non-white student enrollment of the four districts. Table V showed that District A of all four districts had the most students needing improvement or failing in state-wide Grade 5 Mathematics and

Science/Technology tests. The highest gains in the awareness of engineering were achieved in the district with the least prepared students.

**Table XVIII: Pre-Post Gain by School**

| School Number | N | Mean | Std. Deviation |
|---|---|---|---|
| 2 | 11 | 6.55 | 4.06 |
| 5 | 39 | 1.15 | 4.68 |
| 8 | 17 | -0.41 | 6.74 |
| Total | 67 | 1.64 | 5.60 |

Table XIX indicates that School 2 also outperformed the other two schools, though School 5 did show descriptive gains.

**Table XIX: Multiple Between-Groups Comparisons (Tukey HSD)**

| (I) School number | (J) School number | Mean Difference (I-J) | Significance |
|---|---|---|---|
| 2 | 5 | 5.39 | .009 |
| | 8 | 6.96 | .003 |
| 5 | 2 | -5.39 | .009 |
| | 8 | 1.57 | .556 |
| 8 | 2 | -6.96 | .003 |
| | 5 | -1.57 | .556 |

In an effort to determine where the three schools differed in the four domains, further analysis of paired samples t-tests was conducted. Tables XX-XII chart the comparisons and represent the statistical support for the prior indication that the strongest conclusion the data supports is a significant increase in the students' awareness of the occupation of engineering.

As for the individual schools, School 2 of District A recorded the strongest gains in knowledge about engineers, School 5 of District C recorded strong gains in both academics and knowledge about engineering while the scores of School 8 of District C remained essentially flat.

**Table XX: School 2 of District A Summarized by Domain**

| | | Mean | Std. Deviation | Sig. (2-tailed) |
|---|---|---|---|---|
| Pair 1 | Academics: Pre - Academics: Post | -0.14 | 1.35 | .699 |
| Pair 2 | School: Pre – School: Post | -0.14 | 1.35 | .699 |
| Pair 3 | Engineers: Pre - Engineers: Post | 4.73 | 2.87 | .001 |

| | | | | |
|---|---|---|---|---|
| Pair 4 | Aspirations: Pre - Aspirations: Post | 1.36 | 3.05 | .120 |
| Pair 5 | Total: Pre - Total: Post | 6.55 | 4.06 | .000 |

**Table XXI: School 5 of District C Summarized by Domain**

| | | Mean | Std. Deviation | Sig. (2-tailed) |
|---|---|---|---|---|
| Pair 1 | Academics: Pre - Academics: Post | 0.53 | 1.60 | .045 |
| Pair 2 | School: Pre - School: Post | -0.23 | 1.44 | .329 |
| Pair 3 | Engineers: Pre - Engineers: Post | 1.23 | 3.26 | .023 |
| Pair 4 | Aspirations: Pre - Aspirations: Post | -0.36 | 1.58 | .164 |
| Pair 5 | Total: Pre - Total: Post | 1.15 | 4.68 | .132 |

**Table XXII: School 8 of District C Summarized by Domain**

| | | Mean | Std. Deviation | Sig. (2-tailed) |
|---|---|---|---|---|
| Pair 1 | Academics: Pre - Academics: Post | 0.33 | 1.94 | .476 |
| Pair 2 | School: Pre - School: Post | -0.22 | 1.66 | .579 |
| Pair 3 | Engineers: Pre - Engineers: Post | -0.33 | 3.27 | .671 |
| Pair 4 | Aspirations: Pre - Aspirations: Post | -0.41 | 2.43 | .494 |
| Pair 5 | Total: Pre - Total: Post | -0.41 | 6.74 | .804 |

The conclusion by the evaluator that students experienced an increased understanding of the occupation of engineering through participation in this project is a solid finding upon which to build. Because this was the first attempt by the teachers to implement the EiE curriculum, limited gains are not unexpected.

The evaluator's recommendations to THE PROJECT suggest a viable course of action:

- Make a greater effort to ensure that participating students complete both pre- and post-…[surveys of student attitudes]
- Gather data on implementation and devise a manner of ordinating the implementations in terms of their fidelity to an ideal model[10]

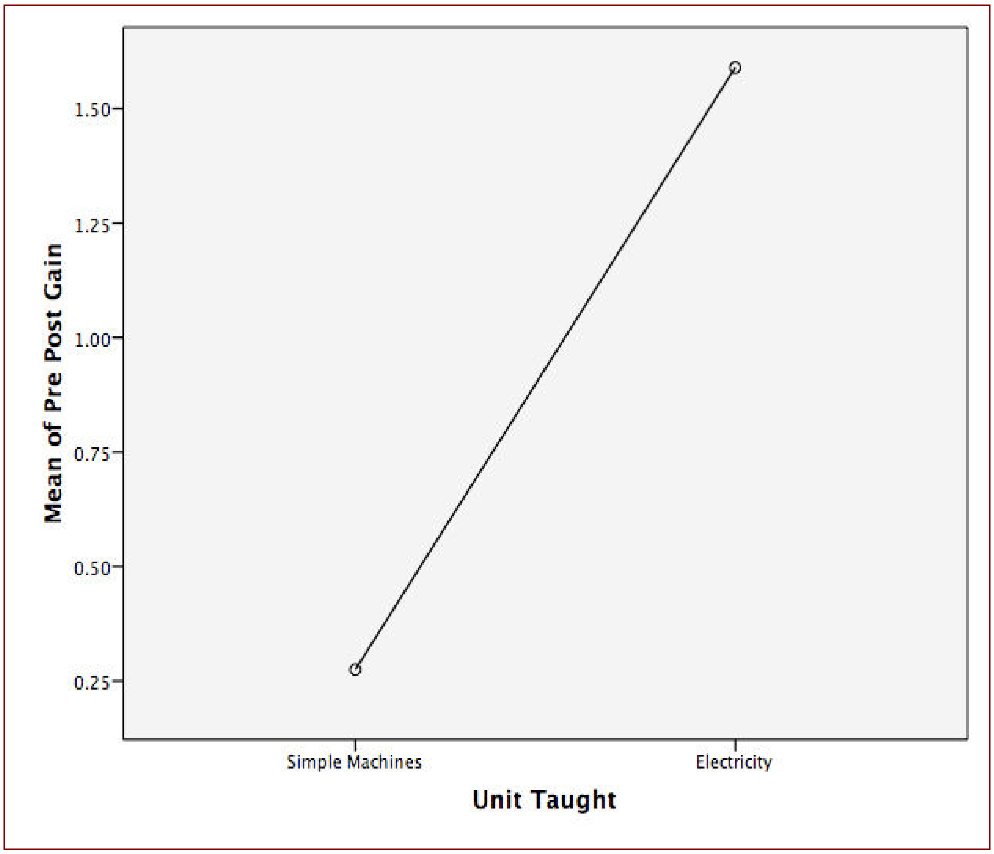
**Evaluation of Gains in Content Knowledge - January through June 2009**

During March, 2009, Teacher C of District B, administered a pre- and post-test of content knowledge using assessments developed by the Boston Museum of Science and included in the Teacher's Guide to the EiE unit. The rest of the lead teachers implemented their units of EiE in April, May or June 2009 and five of them administered to their students the pre- and post-tests of content knowledge supplied with their teacher's guides. In July, 2009, the pre- and post-test scores from the classrooms of the six teachers (three 4th Grade and three 5th Grade) were sent to the evaluator who, on March 8, 2010, submitted an **Interim Evaluation Report**[11].

The pre and post-test scores reported were for two EiE units: "An Alarming Idea" (electricity), experienced by 100 students in Grade 5, and "Marvelous Machines" (simple machines), experienced by a total of 59 students in either Grade 4 in one system or in Grade 5 in the other. The evaluator found that students showed significant gains in content knowledge across sites, units, grades and teachers.

When the evaluator looked at the effect of different units, the EiE unit on electricity was found to produce significantly greater gains than the EiE unit on simple machines.

**Table XXIII: Distribution of Student Gains**



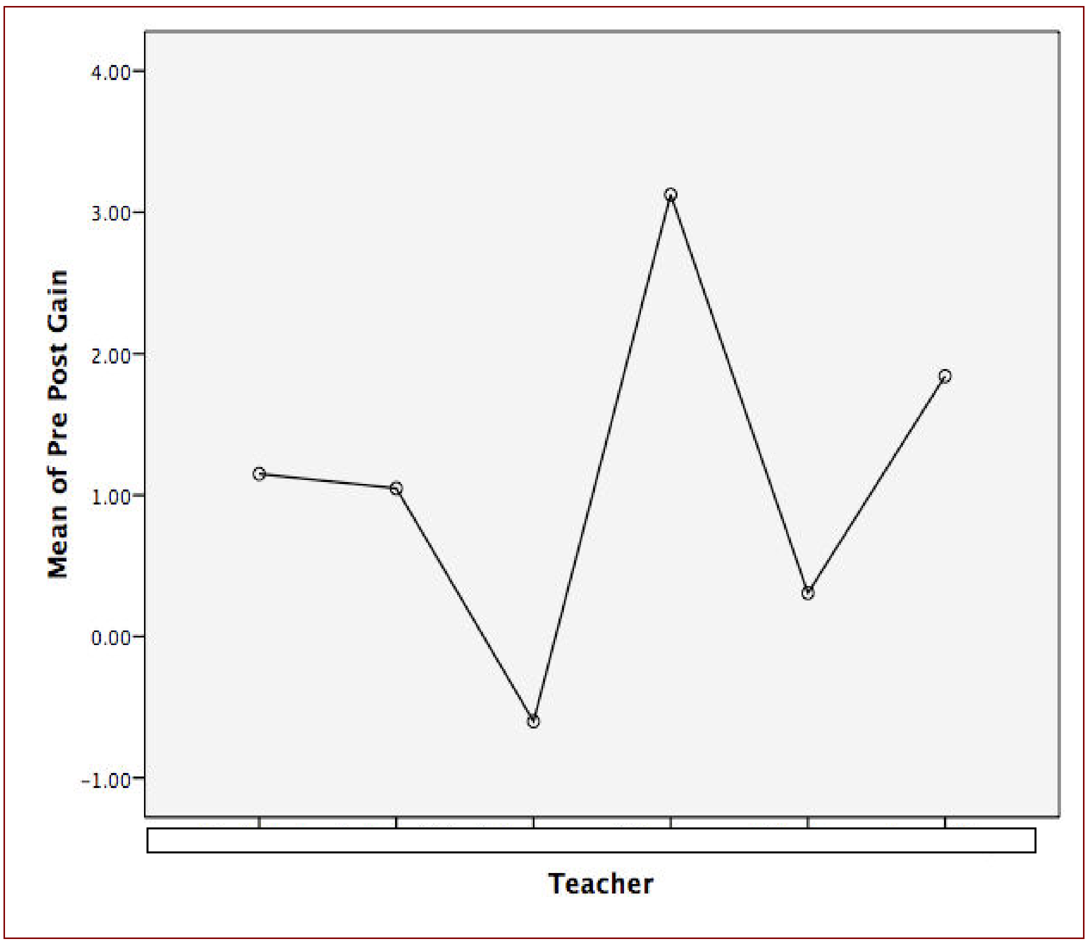

When the evaluator looked at the student gains obtained by the different teachers, one teacher clearly outperformed the others and one teacher clearly underperformed the others. The underperforming teacher later offered by way of explanation that the science material on simple machines had been covered many months before the EiE unit on "Marvelous Machines" had been covered and that the pre- and post-tests of content knowledge had been only separated by the one week in June during which the students worked with the EiE unit.

**Table XXIV: Student Gains by Teacher**

| | N | Mean | Std. Deviation |
|---|---|---|---|
| Teacher 1 | 20 | 1.15 | 1.39 |
| Teacher 2 | 21 | 1.05 | 1.24 |
| Teacher 3 | 20 | -0.60 | 0.99 |
| Teacher 4 | 40 | 3.13 | 2.51 |
| Teacher 5 | 39 | 0.31 | 1.26 |
| Teacher 6 | 19 | 1.84 | 0.60 |
| **Total** | **159** | **1.29** | **2.03** |

Student Gains by Teacher are shown graphically in the following figure, but without the names of the individual teachers.

**Table XXV: Student Gains by Teacher**




Despite the variation by teacher in the average pre-post gains, the evaluator found that the teacher was a relatively less important predictor of student gain than either the grade level of the students or the particular EiE unit. The particular unit of EiE was the most significant predictor of student gain, followed in significance by the grade level.

The evaluator emphasized that the low reporting rate of the participating teachers was a major impediment to a more complete evaluation of student gains in content knowledge. THE PROJECT agrees with this finding and is taking seriously the recommendation to expand the number of teachers submitting complete sets of data.

**Activities after June 2009**

During the summer of 2009, a working group of lead teachers and community college faculty assembled for a one-day Teacher Educator Workshop. Based on their experiences during the 2008-2009 school year which had shown how daunting the administration of pre- and post-surveys of attitude and of pre- and post-tests of content knowledge could be, the group developed a document entitled, **Engineering is Elementary Survey and Assessment Overview**. This document describes the various pre- and post-surveys and pre- and post-tests which will be required of all elementary teachers and their students during Year 2 of the grant and includes a suggested time-line and links to the surveys which are available on-line. Pre- and post-tests of content knowledge are available in the EiE Teacher's Guides issued to each teacher. These Pre- and post-tests of content knowledge will continue to be administered in paper and pencil format .

**Conclusions about Engineering is Elementary**

- There were generally solid increases in students' understanding of the occupation of engineering. However, these gains did not seem to increase positive attitudes about other areas of academics and school, nor did they appear to have increased the students' aspirations to join the field of engineering.
- It is interesting that students in School 2 who exhibited the strongest increases in understanding the occupation of engineering and the strongest aspirations to become engineers are in District A, the only district of the four where the majority of the students have test performance levels of "Needs Improvement" and "Warning/Failing."
- There is little data available on the strength or circumstances of the various implementations of EiE within the four school systems. It is quite likely that under certain conditions the effects on students would be more robust. Given that the current data are drawn from the teachers' first attempt at implementing a highly innovative set of resources and content, it is not surprising that the gains realized in the first year seem to be limited.
- Students made significant gains in content knowledge of the units of EiE across all sites and across the units taught.
- The most important predictor of student success in gaining content knowledge appeared to be the particular unit of EiE. The next most significant predictor of student gain was the grade level. The teacher was a relatively less important predictor of student gain than either the grade level of the students or the particular EiE unit.

## Project Challenges and Insights

- Work with teachers to ensure that participating students complete both pre- and post-tests of content knowledge and pre- and post-surveys of attitudes toward STEM.
- Provide excellent professional development to all the other elementary teachers in the four school districts, professional development that lets each individual teacher learn about engineering, experience the engineering design process and learn how best to implement EiE.
- Tease out specific teacher traits and actions which are most conducive to student success.
- Gather data on implementation, especially on how an individual teacher's implementation corresponds to a model implementation.
- In June of 2009, it was announced that funding for Year Three was being removed because of a fall in state revenues. Without having the carrot of third year grant funding, the biggest challenge will be securing the cooperation of close to two hundred elementary school teachers in the four partnering school districts and the cooperation of the four school districts, especially with regard to getting all the teachers and their students to complete the required pre- and post-tests and pre- and post-surveys. Another challenge will be that there will be no grant funding to refill EiE kits with consumable materials for Year Three. The four partnering school systems will be left on their own to resupply the kits out of their already meager budgets.
- The Project was designed to build to a successful conclusion over three years. With third year funding eliminated three months into Year Two, there is a danger that momentum will begin to build this school year only to come to an early and sudden termination in the spring of 2010. It would be unfortunate if in the 2010-2011 school year there was little additional growth and instead a slow slide backwards in introducing EiE into the elementary schools of the four partnering school districts.
- Some of the insights garnered from this project are not supported by standard statistical analysis as the sample sizes are very limited and a number of uncontrolled variables were present. However, it should also be noted that these conclusions were not drawn from mere anecdotal information but from a thorough evaluation of the best available data.

## Future Activities

- The four school systems will continue to provide professional development to their elementary teachers, an additional 180 or so of whom will implement a unit of EiE in their classrooms over the next year or two.
- To enable further support to the school systems and evaluation of the results, additional funding will be sought from federal stimulus funds which will be distributed to the state through the Governor's office.
- As an inducement to teachers, graduate credit will be offered to elementary teachers who attend the professional development activities, introduce a unit of

EiE into their classrooms, and have their students submit on-line pre- and post-surveys and provide pre- and post-test scores of EiE content knowledge.

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**Appendix[12]**

# Technology/Engineering, Grades 3–5

***Please note:*** Suggested extensions to learning in technology/engineering for grades 3–5 are listed with the science learning standards. See pages 26–29 (Earth and Space Science), 46–49 (Life Science), and 64–66 (Physical Sciences).

LEARNING STANDARDS

**1. Materials and Tools**
*Central Concept*: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

**1.1 Identify materials used to accomplish a design task based on a specific property, e.g., strength, hardness, and flexibility.**
**1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.**
**1.3 Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge, gear, and lever.**

**2. Engineering Design**
*Central Concept*: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.

**2.1 Identify a problem that reflects the need for shelter, storage, or convenience.**
**2.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.**
**2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.**
**2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings.**

# Physical Sciences (Chemistry and Physics), Grades 3–5

| Learning Standard | Ideas for Developing Investigations and Learning Experiences | Suggested Extensions to Learning in Technology/Engineering (Technology/Engineering standards for grades 3–5 are on page 86.) |
|---|---|---|
| **Properties of Objects and Materials** | | |
| **1. Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness).** | Gather a variety of solid objects. Collect data on properties of these objects, such as origin (human-made or natural), weight (heavy, medium, light), length, odor, color, hardness, and flexibility. | *Given a variety of objects made of different materials, ask questions and make predictions about the hardness, flexibility, and strength of each. Test to see if the predictions were correct. (T/E 1.1)* |
| **States of Matter** | | |
| **2. Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.** | Design several stations, each of which demonstrates a state of matter (e.g., water table, balloon and fan table, sand and block table). | *Design one container for each state of matter, taking into account which material properties are important (e.g., size, shape, flexibility). (T/E 1.1, 2.3)* |
| **3. Describe how water can be changed from one state to another by adding or taking away heat.** | Do simple investigations to observe evaporation, condensation, freezing, and melting. Confirm that water expands upon freezing. | *Using given insulating materials, try to keep an ice cube from melting. (T/E 1.1)* |
| **Forms of Energy** | | |
| **4. Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.** | Play music through a speaker with and without a grill cover. Discuss the differences in sound. | *Design and construct a candle wheel that demonstrates how heat can cause a propeller to spin. (T/E 1.1, 1.2, 2.2, 2.3)* |
| **5. Give examples of how energy can be transferred from one form to another.** | Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood. | *Design and build a simple roller coaster for a marble or toy car to demonstrate how energy changes from one form to another. (T/E 2.2, 2.3)* |

# Physical Sciences (Chemistry and Physics), Grades 3–5

| LEARNING STANDARD | IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES | SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING (Technology/Engineering standards for grades 3–5 are on page 86.) |
|---|---|---|
| | **Electrical Energy** | |
| **6. Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound.** | | • Using graphic symbols, draw and label a simple electric circuit. (T/E 2.2)<br>• Using batteries, bulbs, and wires, build a series circuit. (T/E 1.2, 2.2) |
| **7. Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.** | Provide a collection of materials that are good conductors and good insulators. Have students determine each material's electrical conductivity by testing the material with a simple battery/bulb circuit. | *Select from a variety of materials (e.g., cloth, cardboard, Styrofoam, plastic) to design and construct a simple device (prototype) that could be used as an insulator. Do a simple test of its effectiveness. (T/E 1.1, 1.2, 2.2, 2.3)* |
| **8. Explain how electromagnets can be made, and give examples of how they can be used.** | | *Make an electromagnet with a six-volt battery, insulated wire, and a large nail. (T/E 1.2, 2.1, 2.2, 2.3)* |
| | **Magnetic Energy** | |
| **9. Recognize that magnets have poles that repel and attract each other.** | Balance ring magnets on a pencil. Note: The shape of a ring magnet obscures the locations of its poles. | *Design and build a magnetic device to sort steel from aluminum materials for recycling. (T/E 1.1)* |
| **10. Identify and classify objects and materials that a magnet will attract and objects and materials that a magnet will not attract.** | Test a variety of materials with assorted magnets. Include samples of pure iron, magnetic steel, and non-magnetic metals in the materials tested. Mention the two other magnetic metals: pure cobalt and pure nickel. | |

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