The Impact of Engineering is Elementary (EiE) on Students' Conceptions of Technology

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Abstract

This report presents findings from the evaluation of students' concepts of technology before and after participation in an *Engineering is Elementary* (EiE) unit field tested between autumn 2006 and spring 2009, the fourth through sixth years of the EiE project. Students completed a written assessment that asked them to choose whether or not different items were examples of technology. In field test classrooms, students participated in both a related science and an EiE unit, and in control classrooms, students only participated in related science instruction. Compared to control students, students participating in EiE significantly improved their understanding of technology. Additionally, EiE students from all demographic groups tested (gender, race/ethnicity, Individualized Education Program status, and others) improved as much as other students. It was also found that prior to participation in EiE, students tended to believe that technology is anything that is complex or electrical. On the post-test, however, students participating in EiE were more likely than control students to choose non-electrical examples of technology as well as the complex and electrical items.

1 Introduction

In a 2004 Gallup poll, when asked, "When you hear the word 'technology' what first comes to mind?", 68% of Americans answered, "computers" (Rose, Gallup, Dugger, & Starkweather, 2004). No more than 5% of participants provided any other answer. Of course, every day we use hundreds of technologies conceived, designed, and distributed by humans. In order for citizens to engage democratically in many issues of the day, from local construction projects to consumer purchasing decisions to military weapons research, they need to understand technology and the design process broadly (National Academy of Engineering & National Research Council, 2002). In order to build a cleaner, safer world, we need children to think early on about creating and improving a broad definition of technology in its broadest possible definition: objects and processes that are designed by people to solve a problem.

The Engineering is Elementary (EiE) curriculum developed at the Boston Museum of Science introduces elementary school children to a wide range of fields of engineering and technology as a supplement to core science instruction. Every unit begins with a lesson intended to broaden children's definitions of technology beyond only computers and electronics to the idea of something designed by people to solve a problem. The rest of the unit is designed to build on and reinforce a science topic by guiding children through the engineering design of a related technology. By helping children understand that so many things they use, from pencils, to sneakers, to food, are "technologies" devised by engineers, they will become more technologically aware and open to the idea of engineering as a profession.

In this report, we will address the following questions:

1. What are elementary school students' conceptions about technology prior to participation in EiE?
2. How and to what extent does participation in EiE change students' conceptions about technology?

2 Methodology

To measure elementary students' concepts of technology, an instrument was developed and administered in a pre/post-test design to field test and control classrooms. Field test classrooms are those where students were taught an EiE unit and related science, while in control classrooms, students were taught the related science, but not the EiE unit.

2.1 Data Collection

Data collection occurred in both field test and control classrooms over three school years: the 2006-2007 academic year (Year 4 of EiE); the 2007-2008 academic year (Year 5); and the 2008-2009 academic year (Year 6). Participating EiE test and control students received a "What is Technology?" assessment as part of a larger suite of EiE assessments. The results of the other assessments have been reported elsewhere (Lachapelle & Cunningham, 2010; Lachapelle et al., 2011). Every student in a classroom received the same assessments. Where possible, pre-assessments were given in October or November, and post-assessments in May or June of the same school year. However, due to the varying circumstances of individual teachers, sometimes the pre-assessments were given later in the school year or the post-assessments earlier. For example, some assessments were administered by science specialists who saw their students for only a portion of the year. Others were administered by teachers who first learned about the project and signed up to field test an EiE unit in January. In all cases, teachers were instructed to administer pre-assessments before instruction in any EiE unit and related science topics, and post-assessments were administered after all science and EiE instruction was completed. Students were tested twice—once before beginning the science curriculum and/or related Engineering is Elementary unit, and once after instruction was completed—allowing for a test-retest analysis (see Figure 1).

The completed assessments were digitized using an OMR scanner and then imported into a Microsoft Access database. This data was then exported to SPSS Statistics version 19.0, together with student demographic data, for initial analysis.

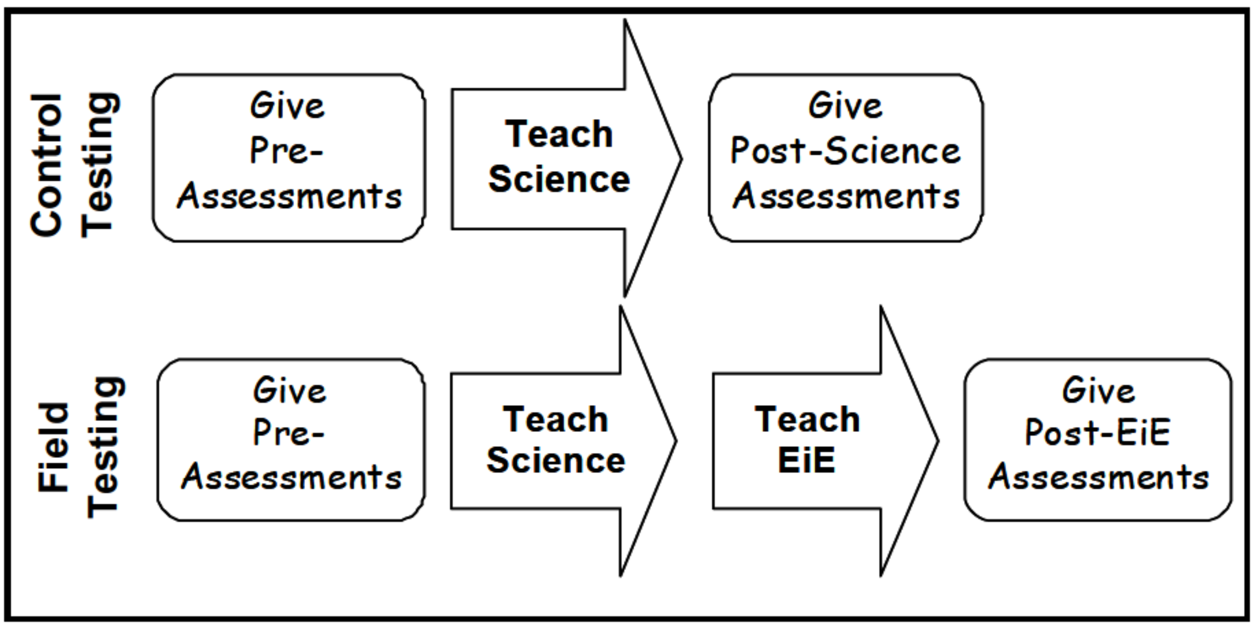

Figure 1. Timing of Assessments in Control and Field Classrooms

2.1.1 Assessment Design

The "What is Technology?" (WT) assessment presents students with drawings and names of various objects, processes, and systems, and asks them to identify which are examples of technology (see Figure 2).

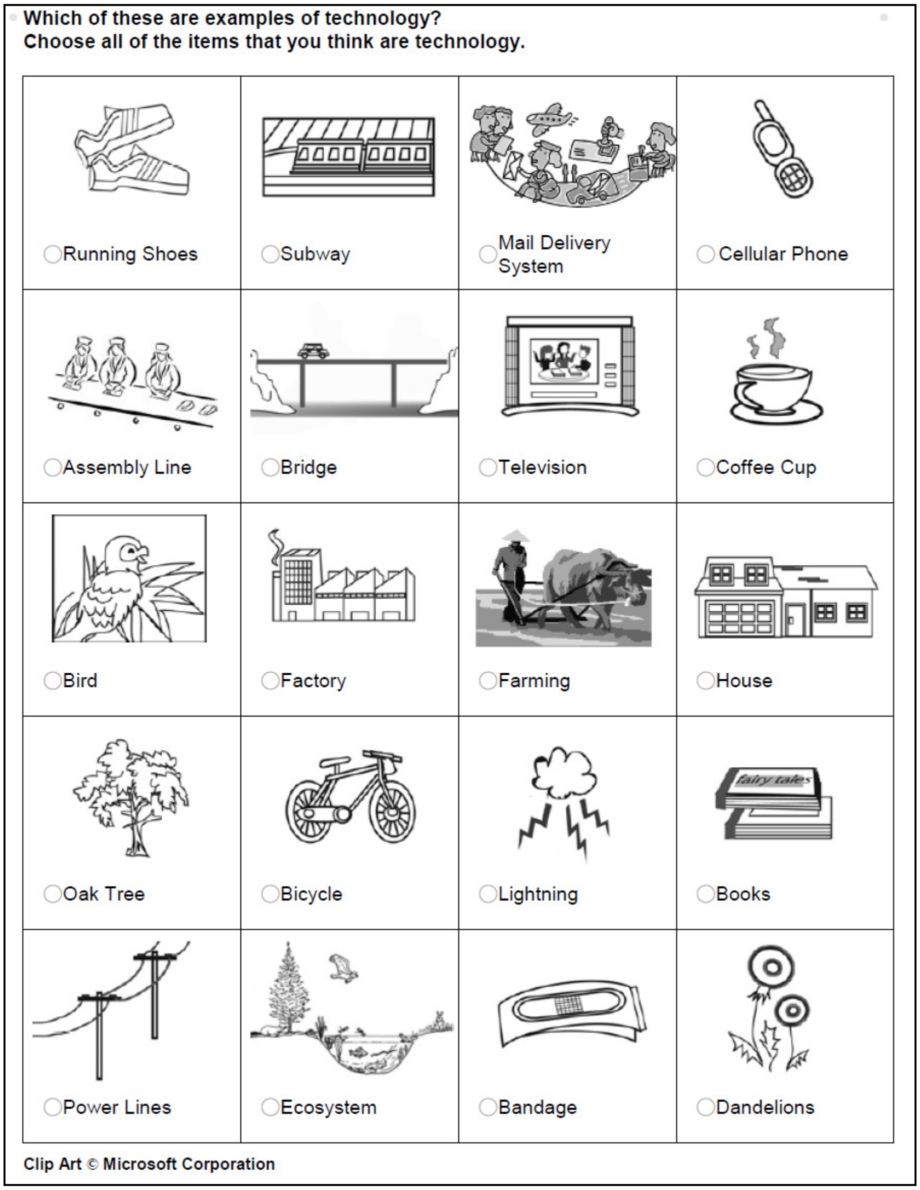

Figure 2. "What is Technology?" Student Assessment

2.1.2 Reliability Analysis and Scale Construction

Student responses to each item were recoded as correct (1) or incorrect (0), and a preliminary scale item was calculated by summing all questions. Initial pre- and post-assessment scores were checked separately for internal reliability and factorability by means of reliability analysis and principal component analysis with direct oblimin rotation in SPSS v19.0. Where scales demonstrated sufficient internal reliability, we used principal component analysis to identify which questions grouped together.

2.1.3 Methods of Analysis

Using SPSS Statistics version 19.0, backward stepwise multiple regression was carried out using the post-test score as the outcome variable and pre-test score as a covariate. This strategy results in an ANCOVA model, where the pre-assessment is used to adjust treatment effect estimates by controlling for differences in pre-assessment scores between the control and treatment sample. Since we were also interested in evaluating whether effects of the curriculum are modified by gender, socio-economic status (as measured by student participation in the National Free and Reduced-Price Lunch (FRL) Program), race, status as an English language-learner with limited English Proficiency (LEP), and participation in an Individualized Education Program (IEP), these demographics were also included as independent variables in the analysis.

In the backward stepwise method of multiple regression, all predictor variables are entered into an ordinary least squares model, and their coefficients are calculated. Each coefficient has a standard error associated with it, which is used to perform a t-test to determine the statistical significance of the coefficient. The least statistically significant predictor variable is removed, and the regression is recalculated. This process is repeated until only statistically significant predictors remain in the model. We then calculated Cohen's *d* for a given demographic or treatment effect by dividing the coefficient of the binary variable in question by the standard deviation of the residuals of the conditional model. This corresponds with the standard calculation of Cohen's *d*, in that the coefficient of a binary variable serves as the difference between the means of the two populations, while the standard deviation of the conditional model residuals serves as the pooled standard deviation of the two populations after controlling for any other factors.

3 Results

3.1.1 Scale Construction: "What is Technology?"

We constructed scales and calculated internal reliability for the "What is Technology?" instrument using a sample of 1266 students (495 control and 771 test students) who had participated in field testing during years 4, 5, and 6 of the EiE project and had completed both a pre- and post-assessment. Since students are not likely to be familiar with the definition of technology prior to EiE, we expect lower reliability on the pre-test due to random guessing.

For each item on the assessment, student responses were converted to a score of correct (1) / incorrect (0). These scores were summed, and the resulting overall scale analyzed for internal–consistency reliability. Reliability measured on the post-assessments (both test and control) was high (PostWT Cronbach's alpha = .791), and reliability measured on the pre-assessments was also acceptably high (PreWT Cronbach's alpha=.740).

Prior analysis of this assessment had led us to consider excluding the item Lightning as interviews with students suggested that children hold wide-ranging and sometimes conflicting ideas about Lightning. Internal reliability analysis of the overall scale excluding lightning (ReducedWT scale) gave a Cronbach's alpha of .750 for the pre-assessments and .787 for the post-assessments, indicating a high level of reliability.

Principal components analysis of the ReducedWT scale showed that factorability indicators were high (Bartlett's Test of Sphericity $p<.000$ and KMO = .875). The scree plot and component matrix indicated that there were 4 components which together explained 51.1% of the variance. These components roughly divide into the following categories: technologies not requiring electricity (SimpleTech); technologies requiring energy (EnergyTech); systems (SystemTech); and natural non-technologies (NotTech). The components and the variables that load onto them are shown in Table 1.

Table 1. PCA Components: PostReducedWT Scale

Component 1: SimpleTech	***Component 2: EnergyTech***	***Component 3: SystemTech***	***Component 4: NotTech***
Running Shoes Bandage Books Tea Cup Bicycle House Bridge	Television Power Lines Cellular Phone Factory	Assembly Line Mail Delivery System Subway Farming	Bird Dandelion Oak Tree Ecosystem

3.1.2 Sample: "What is Technology?"

We collected *"What is Technology?"* (WT) assessments from 2793 students (892 control and 1901 test) in 124 classrooms (grades 3-6). However, 54.7% of the sample (n=1527) was excluded because they were missing a pre-assessment or a post-assessment. This corresponds to 44.5% of the control sample (n=397) and 59.4% of the test group (n=1130). Additionally, 174 students were excluded due to missing demographic information. Thus the final dataset used for analysis included 1092 students (620 test and 472 control) in 56 classrooms (33 test and 23 control).

Table 2 shows the classroom grade distribution for the test and control groups. The majority of control classrooms were grade 3 and 5 classrooms (39% and 31%, respectively), while the majority of test classrooms were grade 5 classrooms (46%).

Table 2. Classroom Grade Distribution

Treatment		**Grade 3**	**Grade 4**	**Grade 5**	**Grade 6**
Control	Proportion	.39	.17	.31	.13
	N	9	4	7	3
Test	Proportion	.15	.36	.46	.03
	N	5	12	15	1
Total	Proportion	.25	.29	.39	.07
	N	14	16	22	4

Table 3 and Table 4 show the demographic information for the test and control groups. Compared to the control group, the test group had a higher proportion of LEP students and a lower proportion of FRL students (see Table 3). The control and test groups also differed in racial composition. White students made up 61% of the test group, but only 44% of the control group. Additionally, there were more Black, Asian, and Hispanic students in the control group as compare to the test group (see Table 4).

Table 3. WT Proportions for Demographic Variables

Treatment		Gender (male)	LEP	FRL	IEP
Control	Proportion	.50	.07	.46	.10
	N	238	33	216	48
Test	Proportion	.49	.14	.37	.09
	N	303	85	229	56
Total	Proportion	.50	.11	.41	.10
	N	541	118	445	104

Table 4. WT Proportions for Demographic Variables – Race

Treatment		White	Asian	Black	Hispanic	Other	Total
Control	Proportion	.44	.10	.15	.27	.04	1.0
	N	205	49	72	125	21	472
Test	Proportion	.61	.05	.09	.21	.04	1.0
	N	377	34	55	129	25	620
Total	Proportion	.53	.08	.12	.23	.04	1.0
	N	582	83	127	254	46	1092

3.1.3 Results: "What is Technology?"

For the "*What is Technology?*" assessment, responses from students participating in EiE (test sample) were compared to responses from a control sample. The pre-assessment scores were used as a covariate, and were group-mean centered. Group-mean centering, rather than grand-mean centering, was used because (1) it allows us to compare each student to their own class, so the relationship between pre- and post-assessment scores becomes better specified, and (2) it allows us to interpret the grand intercept as the average class score on the post-assessment, rather than the average student score.

We computed the PostReducedWT outcome variable by adding together the number of correct answers for all 19 items on the ReducedWT scale (excludes Lightning). This variable was used to test for a treatment effect on the performance of students on the ReducedWT assessment and had a possible range of 0 to 19. The mean PreReducedWT scores were slightly higher for the test group compared to the control group (11.2 and 10.1, respectively). The test group also had a larger mean PostReducedWT score (15.0) than the control group (11.1) (see Table 5).

Table 5. WT Descriptive Statistics: PreReducedWT and PostReducedWT Scores by Treatment

	PreWT				PostWT			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Control	10.1	2.48	4	19	11.1	2.93	4	19
Test	11.2	3.08	4	19	15.0	3.08	4	19

Using the backward step-wise method, a significant model emerged: F (7, 1084) = 110.041, $p < .001$. The model explains 41.2% of the variance (Adjusted $R^2 = .412$). Table 6 gives information about the unstandardized (B) and standardized (β) regression coefficients along with the standard error (SE B), t-value, and p-value for each predictor variable that was included in the model.

Table 6. Summary of variables included in the PostReducedWT Scale Model

Variable	B	SE B	β	t-ratio	p-value	Cohen's *d*
(Constant)	11.983	.161		74.445	<.001	
PreReducedWT	.465	.052	.374	8.898	<.001	
PreReducedWT_by_Treatment	–.175	.063	–.114	–2.783	.005	
FRL	–.441	.208	–.060	–2.121	.034	–0.161
Asian	–.904	.331	–.067	–2.729	.006	–0.329
Black	–.905	.294	–.081	–3.080	.002	–0.330
Hispanic	–.750	.240	–.088	–3.130	.002	–0.273
Treatment	2.208	.386	.322	5.721	<.001	0.804

This model shows evidence of a main treatment effect ($p < .001$) with a large Cohen's *d* effect size of 0.804. Figure 3 shows the predicted post-test scores on the Reduced WT scale. Although scores are predicted to be lower for Asian, Black, Hispanic, and FRL students, this effect was not moderated by treatment. EiE students in these demographic groups still improved over control students from the same demographic groups and are also likely to perform better than control students in the reference group (those students who are not Asian, Black, Hispanic, or FRL).

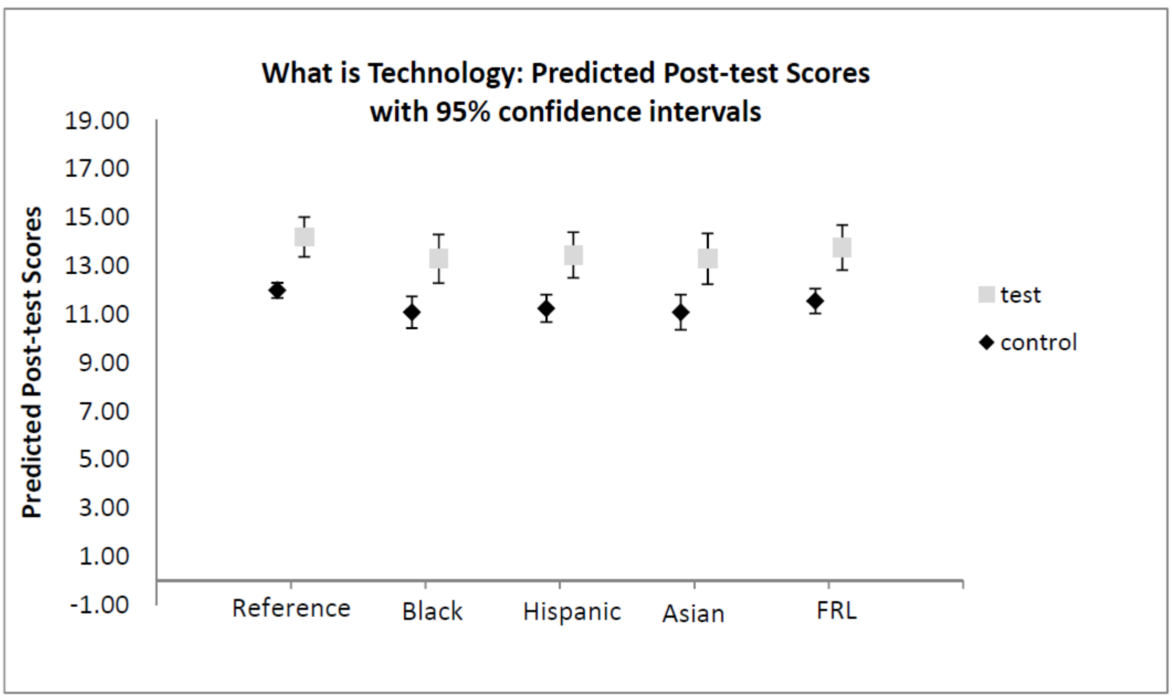

Figure 3. Predicted Post-test Scores on the ReducedWT Scale

To further investigate students' conceptions of technology, we examined how the frequencies of answers on the WT assessment changed from the pre-assessment to the post-assessment (see Figure 4). The questions are arranged in order of increasing frequency of being chosen on the pre-assessment.

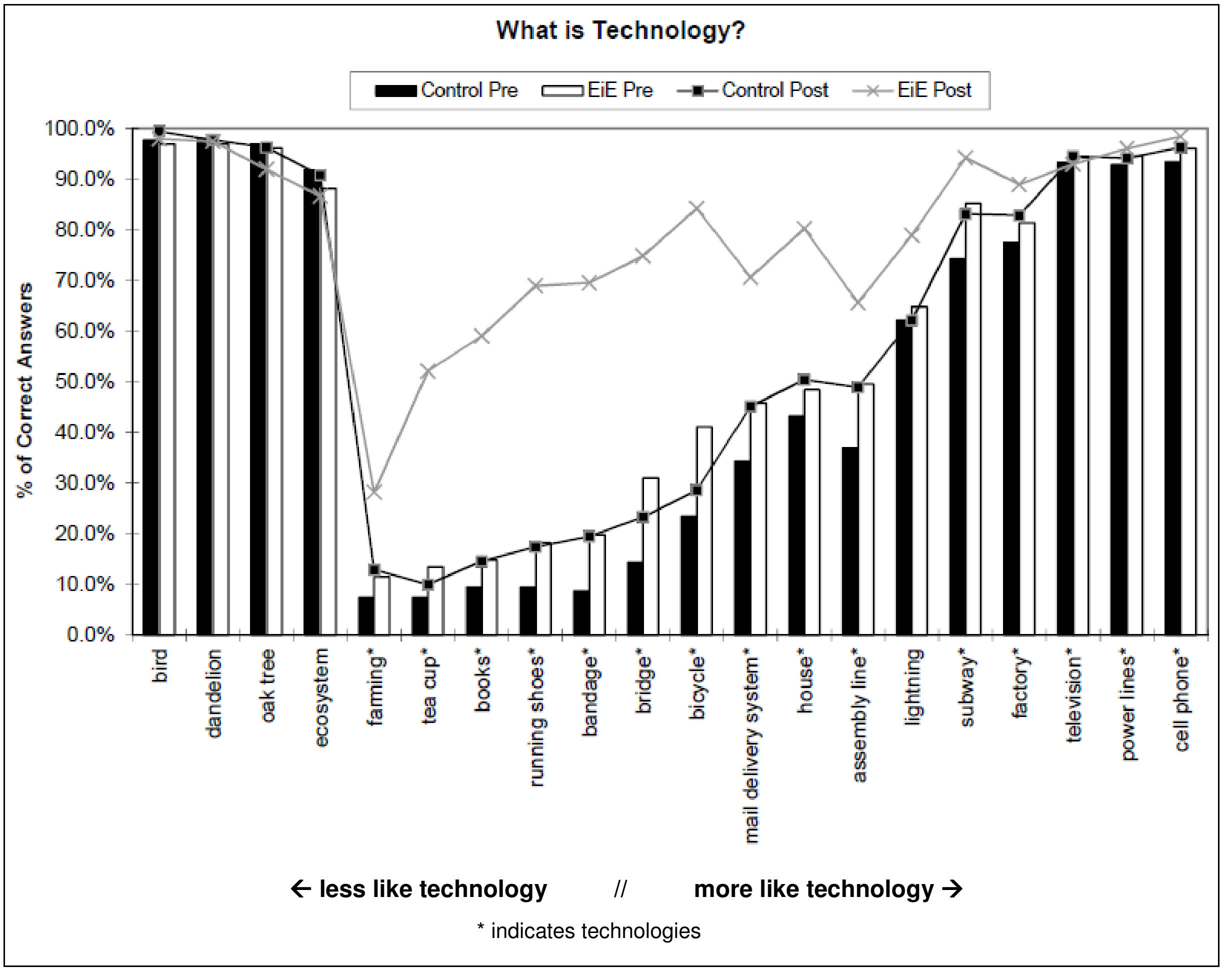

Figure 4. Student Responses Pre vs. Post: What is Technology?

It is clear that before participating in an EiE unit, students mostly thought that technology was anything electrical or complex – for example, 93.4% of control students and 96.0% of test students thought a cell phone was an example of technology (see Figure 4), while only 8.7% of control students and 19.8% of test students thought a bandage was an example of technology (see Figure 4). After participating in EiE, the students have a much better understanding of what technology is – 69.5% of test students chose "bandage" as an example of technology of the post-assessment, while only 19.8% of control students did the same.

As shown in Figure 4, students in both groups did not think that living things like birds were examples of technology either on the pre- or the post-assessment. The one exception is lightning–37.9% of control students and 35.2% of test students thought that lightning was a technology on the pre-test. Since Figure 4 shows that students strongly associate electrical items with technology, they may be choosing lightning because they see it as a form of electricity.

4 Summary

Our analysis suggests that students participating in an EiE unit improved their understanding of technology. The effect of participating in an EiE unit as measured by the "What is Technology?" instrument is high (Cohen's d=0.804). Additionally, it appears that prior to participation in EiE, students believe that technology is anything that is complex or electrical. On the post-test, however, students participating in EiE are more likely than control students to choose non-electrical examples of technology as well as the complex and electrical items.

5 References

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