Elementary Students' Engineering Interests and Attitudes: Demographic and Treatment Differences

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Abstract

Students in grades 3-5 were asked to rate their interest in and attitudes towards engineering after participating in a school-year engineering curriculum unit, as compared to their remembered interest and attitudes of the summer before. The Engineering Interests and Attitudes (EIA) survey has six subscales, and its development and characteristics are described in detail in [Authors] (2018). The survey was administered as part of a large-scale RCT study of an engineering curriculum for elementary school students. In this paper, we report student outcomes on the assessment for treatment and control, as well as gender and other demographic differences in outcomes. Generally we found that students reported becoming more positive in their interests and attitudes after participating. We find no treatment difference on scales where students rate the value of engineering to themselves and society, but we find that students in the treatment group show less gender bias after the curriculum intervention than control, and less interest in becoming an engineer. Females are more positive than males on all scales. Time spent on the engineering unit, the percent completion of student journals, teacher experience in general and with teaching engineering, and the class average quality of student responses in journals all predict more positive outcomes.

Subject

In recent years, there has been concern about the shortfalls in the numbers of American students pursuing engineering and other technical careers in the United States (National Academies of Sciences, Engineering, and Medicine, 2017) and the diversity among those entering engineering fields (Buccheri, Gurber, & Bruhwiler, 2011; National Academy of Sciences, National Academy of Engineering (NAE), & Institute of Medicine, 2010; National Research Council & NAE, 2014). Ongoing efforts have aimed to increase the awareness and interest of K-12 students in engineering. Such efforts take the form of in-school curricula and interventions for engineering education, as well as out-of-school programs and activities. The expected effect of such curricula and programs is that, once K-12 students are exposed to the ideas and practices of engineering, they will become more interested in pursuing a career in engineering, and more positive about the potential impact of engineering on human concerns. Engaging young children in the work of engineering could help children develop more accurate and positive attitudes toward engineering. Research has documented that children settle on career paths long before middle school; engineers and scientists often choose this path before adolescence (Lindahl, 2007; Lyons, 2006; Tai, Liu, Maltese, & Fan, 2006; Venville, Wallace, Rennie, & Malone, 2002).

Purpose of the Research

Data for this research paper was collected as part of the Exploring the Efficacy of Engineering is Elementary (E4) study, a large-scale efficacy study implemented as a randomized controlled trial (RCT), with schools randomized into either the treatment or comparison group. The two groups received curricula that addressed the same learning goals but differed on a number of "critical components" related to project-based learning methods (Krajcik & Blumenfeld, 2006), engagement in science and engineering practices, and sociocultural approaches to learning (see Table 1). The treatment group used the Engineering is Elementary (EiE) curriculum. The intention of the efficacy study was to determine if the critical components are more effective at improving student outcomes than a control "curriculum."

Table 1. Critical components of [Treatment Curriculum] as compared to [Control Curriculum].

[Treatment Curriculum]	[Control Curriculum]
Engineering content is introduced in a narrative context, designed to appeal to children from diverse backgrounds.	Engineering content is introduced in traditional textbook style. No context is provided for the challenge.
Students use a specified engineering design process.	Students are not explicitly taught an engineering design process.
Engineering challenges identify a problem with constraints and specifications for the solution requiring trade-offs.	Constraints and specifications for successful solution of the engineering challenge are not given. Trade-offs are not required.
Students use science and math as they design solutions.	Science and math are not explicitly featured nor is their use supported.
Students analyze data and use failure constructively as they design iteratively.	Students are not supported to analyze data or reflect on failures. Designs are not improved.
Students' collaborative work is supported and includes negotiating with team members	Students may work together in teams but are not given support to do so.
Students are encouraged to be creative, brainstorm, and consider a multiplicity of ideas and possible solutions.	The design challenge is open-ended but development of multiple design ideas is not discussed or supported in the curriculum.
Teacher guide supports engaging prior knowledge, prompting reflection, and modeling engineering thinking and practices.	Teacher guide focuses on how to explain content to students and the specifics of running the activity.

For the treatment curriculum, four EiE units—electrical, environmental, geotechnical, and package engineering—were chosen. The comparison curriculum, which we named Engineering for Children (E4C), was compiled from activities freely available on the internet. We matched the two curricula with respect to unit focus (we developed one E4C unit for each selected EiE unit), learning objectives, and time for implementation. Teachers implemented one of these units based on the science topics they addressed. Student assessment data were collected before and after the unit. A fifth unit focused on civil engineering was also implemented by about half of the teachers as we wanted to examine whether familiarity with engineering influenced student outcomes. No data specific to the civil engineering unit were collected.

In this paper, we examine the effects of EiE versus E4C, as well as class- and school-level variables and treatment by demographic interactions, on student interests in and attitudes towards engineering, using the Engineering Interests and Attitudes (EIA) survey. Our goal is to elucidate the overall effects of engineering lessons and demographic variables, as well as the relative effects of each pedagogical approach on these student outcomes, in pursuit of our larger goal of examining the efficacy of EiE and its pedagogical design through its impact on student outcomes.

Our research questions are:

1. How do the two engineering curriculum treatments affect children's interest in and attitudes towards engineering?
2. Is there a difference in EIA outcomes between the two treatments?
3. What demographic differences at the student, teacher, and school levels predict children's interest in and attitudes towards engineering following an engineering intervention?

Theoretical Framework

A sociocultural perspective on learning grounds the Engineering is Elementary curriculum (Lemke, 2001; Vygotsky, 1978; Wertsch, 1985)—students learn by actively participating in social communities. Carefully structured experiences can afford students an opportunity to interact with and learn from peers and educators who are more experienced or knowledgeable. Curriculum should focus on purposeful activity and encourage students to talk, write, interact, and work with peers (Kelly & Green, 1998; Mortimer & Scott, 2003). Engaging in disciplinary discourse and practices helps students to make sense of their experiences and can result in learning. Throughout, students are drawing upon concepts, tools, texts, technologies, and practices that are relevant to a specific field or setting. Interactions with other more-knowing members of the class in a variety of configurations—pairs, groups, whole class—allow students to use physical materials, manipulate ideas and concepts, and use language to construct understandings of the engineered world and engineering practices that are consistent with those of the larger disciplinary community (Kelly & Licona, 2018).

Design

Design of the E4 Study

More than 600 teachers applied to participate in the E4 study. They were recruited through the principals of their schools and superintendents of their districts, and participated with the permission of administrators. Teachers were encouraged to apply as teams of teachers from the same grade, because the E4 study was designed to have teachers participate for two consecutive years, with new classes of students each year. Schools, not teachers, were randomized into either the EiE treatment condition or the control group, to avoid cross-contamination of treatments.

Teachers received professional development, separately by treatment group, to support them to implement their engineering units during the summer before Year 1 of implementation, and again during the summer before Year 2. Half of teachers in each unit were assigned to teach a second, un-assessed engineering unit, the civil cngineering unit, in the treatment version they were assigned (EiE or E4C), as an additional dose of engineering. All teachers were counseled on how to implement their assigned curriculum with fidelity. During the school year, teachers were required to, in order, (1) collect and submit demographic information for their students; (2) complete and return student pre-assessments; (3) teach required science content using their own materials; (4) teach their assigned engineering unit; (5) complete and return student post-assessments and engineering journals. The EIA survey that is the subject of this paper was completed by students in step (5) with the science and engineering post-assessments.

Instrument Characteristics

To measure the effect of the EiE curriculum on students as compared to the control group, we used the EIA survey, which is found to have strong evidence for the validity of such a use (Lachapelle & Brennan, 2018). The survey includes six subscales, measuring (1) a student's enjoyment of doing engineering in school (Enjoyment); (2) the value of engineering to the student (Value to me); (3) the student's interest in school engineering (School); (4) the student's perception of the value of engineering to society (Value to society); (5) the student's aspirations to be an engineer or learn more engineering in future (Aspirations); and (6) the student's engineering gender biases (Gender bias). The instrument includes 24 items contributing to six scales. It is implemented as a post-only Likert-scale survey with five choices per item: "strongly disagree," "disagree somewhat," "not sure," "agree somewhat," and "strongly agree." Students were asked to answer each question twice: once to the prompt "Last summer, I would have said:" (which we name PRE hereafter) and also to the prompt "Now I would say:" (NOW). We chose to use this "retrospective pre" design because we knew from our prior work that children were unlikely to understand questions about engineering prior to instruction, and other researchers have chosen this survey format to mitigate similar problems (e.g., Bhanji, Gottesman, de Grave, Steinert, & Winer, 2012; Sibthorp, Paisley, Gookin, & Ward, 2007). Table 2 shows the disattenuated correlations between the factors.

All factors except Gender bias were positively correlated ($p<.001$), indicating that students with positive scores on one subscale tended to have positive scores on all five. A positive gender bias score indicates more bias; correlations show that before the intervention (PRE), student gender bias was unrelated to attitudes and interest, but after the intervention (NOW), students with more positive scores on the other subscales also tended to indicate less biased gender attitudes.

Table 2: Disattenuated correlations between factors PRE/NOW

Factor	Enjoyment	Value to me	School Eng	Value to society	Aspirations
Enjoyment	1.00				
Value to me	.791**/.621**	1.00			
School Eng	.899**/.840**	.754**/.720**	1.00		
Value to society	.768**/.584**	.668**/.612**	.887**/.762**	1.00	
Aspirations	.932**/.891**	.702**/.566**	.819**/.734**	.732**/.539**	1.00
Gender bias	.009 /-.105**	-.013 /-.148**	-.060* /-.208**	-.041 /-.180**	-.021 /-.046[t]

[t]p<.05; * p<.01; **p<.001

Factor determinacies for the refined factor scores were derived in Mplus (Muthén & Muthén, 2015—see Table 3). All factor determinacies exceed the threshold of 0.8, indicating good quality and replicability. Seven of twelve exceed the preferred threshold of 0.9.

Table 3: EIA survey factor determinacies

	Enjoyment	Value to me	School	Value to society	Aspirations	Gender bias
PRE	0.934	0.865	0.918	0.908	0.908	0.858
NOW	0.939	0.839	0.917	0.873	0.936	0.876

Data Collection

For the E4 study, we collected EIA post-implementation surveys from 10,906 students in grades 3, 4, and 5; however, only 6923 were used in this analysis, as some surveys were missing data and excluded from the analysis. Students included in the analysis represented a wide range of demographic characteristics (Table 4).

Explanatory Modeling

With an RCT, we are able to make an argument that any treatment differences we find are caused by the treatment. We checked for homoscedasticity and normality of errors. We also checked the relationship between predictors and outcome variables, which we found to be linear.

We chose predictor variables based on their theoretical relevance to the constructs of attitudes towards and interest in engineering, and based on our research questions. These variables and their descriptors are given in Table 4. Prefixes for each variable indicate the level of measurement: S_ for student-level variables; C_ for variables measured at the class level; T_ for teacher-level variables, and O_ for school-level variables.

Because we want to compare the treatment and control groups (research question 2), we include a treatment variable (O_Treat). To further specify the type and quality of treatment in each class, we also include C_Year2, to indicate what year of the study the data comes from; C_Unit, specifying which engineering topic and learning objectives; C_Grade, to indicate the age of the students; C_JQCode, as a measure of the class-level quality of engineering journals containing student written work; and T_Civil which indicates whether a teacher was assigned to additionally teach the Civil Engineering unit to all of his or her classes.

Table 4: Descriptors for predictor variables: categorical and continuous.

Variable	Description	Percent	Variable	Description	Mean
S_Female	Female	.492	S_Pre_EIA	Student self-score PRE	.007
S_Race	White	.776	S_JCmplt	% of student journal completed	.925
	Asian	.024			
	Black	.096	C_JQCode	Quality of journals in this class	8.091
	Hispanic	.058			
	Other	.046	T_NYT	Teacher: # of years teaching	11.62
S_Books	Few (0-10 books)	.122			
	A shelf (11-25 books)	.195	O_FRL	% of school gets FRL	.456
	A bookcase (26-100 books)	.318			
	Several bookcases (>100)	.365			
C_Year2	Second year of E4 Study	.443			
C_Unit	Environmental engineering	.333			
	Electrical engineering	.248			
	Geotechnical engineering	.168			
	Package engineering	.251			
C_Grade	Grade 3	.293			
	Grade 4	.327			
	Grade 5	.380			
T_Civil	Extra dosage engineering	.508			
O_Treat	EiE curriculum treatment	.437			

Note: The prefix S_ marks student-level variables; C_ marks class-level, T_ marks teacher-level, and O_ marks school-level variables.

Our third research questions asks what relationships we see between demographic variables and students' self-rated interests and attitudes following their engineering lessons. To examine these relationships, we include the following student-level variables: S_Female, to distinguish gender differences; S_Race, to distinguish racial/ethnic differences; S_Books as a proxy measure of socio-economic status; and S_JCmplt, engineering journal completion as a measure of student engagement, under the assumption that students who complete more of their journals will have been more engaged in the engineering lessons. We include one teacher-level demographic, T_NYT, a measure of teaching experience, and one school-level demographic variable, which may predict differences in interest and attitude outcomes, but which we could not collect sufficient data to measure at the student level: O_FRL, a measure of the extent to which a school serves low-income students.

For each of our five factors (scale variables), we calculated a general linear regression to predict the NOW scale dependent variable (DV) based on the predictor variables listed in Table 4. Missing data was excluded.

Results

Our first research question addresses the overall pattern of results for treatment and control groups (Table 5). Mean scores for the total sample are zero, because these variables are standardized. For both treatments, we see that the NOW scores are improved compared to the PRE scores, indicating more positive interest and attitudes, and less gender bias.

Table 5. PRE and NOW mean scores by treatment group.

		PRE / NOW			
Outcome scale	Treatment	Mean	Std. Deviation	Minimum	Maximum
Value to Me	E4C	.027 / .967	.4448 / .3582	-1.05 /-.90	1.06 / 1.34
	EiE	-.034 /.923	.4517 / .3791	-1.05 / -.89	1.06 / 1.34
School	E4C	.046 / 1.217	.8214 / .5685	-2.10 / -1.81	1.85 / 1.84
	EiE	-.057 / 1.130	.8317 / .6124	-2.09 / -1.77	1.85 / 1.84
Aspirations	E4C	.060 / 1.032	.9592 / .9176	-2.04 / -2.23	2.11 / 2.06
	EiE	-.073 / .878	.9856 / 1.0026	-2.04 / -2.27	2.15 / 2.07
Enjoyment	E4C	.062 / 1.427	.9550 / .790	-2.20 / -1.95	2.21 / 2.28
	EiE	-.076 / 1.282	.9751 / .871	-2.20 / -1.95	2.21 / 2.26
Value to Society	E4C	.038 / 1.100	.7151 / .4733	-1.87 / -1.53	1.59 / 1.63
	EiE	-.048 / 1.039	.7236 / .5007	-1.85 / -1.50	1.60 / 1.63
Gender Bias	E4C	-.003 / -.262	1.0002 / 1.0567	-1.21 / -1.41	2.19 / 2.46
	EiE	.012 / -.281	1.0027 / 1.0146	-1.23 / -1.38	2.19 / 2.38

To examine our second research question, we look at the effect of treatment (Table 6). At the school level, students in the experimental treatment (O_Treat) are predicted to have lower interest in school engineering, lower aspirations to become engineers, and less enjoyment of engineering than students in the control group. However, the treatment group students are also predicted to have less gender bias than the control group. Scores for both treatments are the same for the “Value to Me” and “Value to Society” scales.

Table 6: Coefficients for each predictor variable for the outcome model for each EIA scale.

	Value to Me		School Eng.		Aspirations		Enjoyment		Value to Society		Gender Bias	
Variables	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Intercept	**0.494**	**.000**	**0.428**	**.000**	-0.005	.954	**0.432**	**.000**	**0.444**	**.031**	**0.277**	**.001**
S_Female	**0.048**	**.000**	**0.093**	**.000**	**0.057**	**.006**	**0.093**	**.000**	**0.056**	**.000**	**-0.221**	**.000**
S_Race (White is default)												
Asian	-0.009	.736	-0.044	.320	-0.105	.121	-0.101	.094	-0.001	.977	-0.069	.238
Black	**-0.086**	**.000**	**-0.151**	**.000**	**-0.174**	**.000**	**-0.186**	**.000**	**-0.118**	**.000**	**0.146**	**.000**
Hispanic	-0.007	.714	0.020	.488	0.024	.587	0.021	.596	0.009	.702	0.017	.664
Other	0.014	.495	0.018	.582	0.029	.558	0.030	.501	0.009	.728	0.005	.908
S_Books (0-10 is default)												
11-25	**0.053**	**.001**	**0.066**	**.007**	**0.083**	**.026**	**0.090**	**.007**	**0.051**	**.012**	-0.063	.053
26-100	**0.105**	**.000**	**0.163**	**.000**	**0.157**	**.000**	**0.182**	**.000**	**0.143**	**.000**	**-0.191**	**.000**
>100	**0.112**	**.000**	**0.169**	**.000**	**0.149**	**.000**	**0.177**	**.000**	**0.163**	**.000**	**-0.221**	**.000**
S_PRE_EIA	**0.186**	**.000**	**0.197**	**.000**	**0.398**	**.000**	**0.294**	**.000**	**0.173**	**.000**	**0.648**	**.000**
S_JCmplt	**0.209**	**.000**	**0.370**	**.000**	**0.418**	**.000**	**0.432**	**.000**	**0.297**	**.000**	**-0.231**	**.003**
C_Year2	0.012	.160	0.022	.109	**0.078**	**.000**	**0.042**	**.025**	**0.023**	**.041**	0.000	.997
C_Unit (Environmental engineering is default)												
Electrical	**-0.035**	**.008**	**-0.065**	**.002**	**-0.069**	**.030**	**-0.069**	**.015**	**-0.056**	**.001**	**0.094**	**.001**
Geotechnical	**-0.048**	**.000**	**-0.114**	**.000**	**-0.176**	**.000**	**-0.152**	**.000**	**-0.086**	**.000**	0.029	.281
Package	0.008	.569	0.020	.331	0.059	.064	**0.071**	**.013**	-0.012	.495	-0.024	.391
C_Grade (Grade 3 is default)												
Grade 4	**-0.040**	**.002**	**0.069**	**.001**	**0.089**	**.004**	0.092	.514	**0.062**	**.000**	**-0.064**	**.016**
Grade 5	-0.011	.373	0.011	.589	**-0.063**	**.034**	**-0.017**	**.001**	0.029	.076	**-0.152**	**.000**
C_JQCode	**0.016**	**.000**	**0.026**	**.000**	**0.041**	**.000**	**0.035**	**.000**	**0.026**	**.000**	-0.008	.104
T_Civil	**0.017**	**.045**	**0.036**	**.008**	**0.053**	**.011**	**0.059**	**.001**	0.019	.089	-0.011	.523
T_NYT	**0.002**	**.000**	**0.002**	**.006**	**0.004**	**.002**	**0.003**	**.013**	**0.002**	**.002**	-0.002	.083
O_Treat	-0.016	.090	**-0.042**	**.003**	**-0.080**	**.000**	**-0.083**	**.000**	-0.020	.098	**-0.072**	**.000**
O_FRL	-0.008	.645	-0.005	.861	**0.181**	**.000**	**0.081**	**.037**	**-0.059**	**.011**	**0.246**	**.000**

To answer our third research question, we examine the effects of demographic variables as predictors. In Table 6, we show that some predictors have consistently positive or negative effects on all of the EIA scales, while others affect only some scales. Female students and students with more books in the home consistently score higher on all the attitude and interest scales and lower on the gender bias scale, while black students show the opposite pattern. Students who complete more of their engineering journals also have more positive attitudes and interest along with lower gender bias.

At the class level, we see that classes participating in the second year of the study (whose teachers are no longer new to teaching engineering) have students with higher Aspirations as well as more positive Enjoyment and attitudes about the value of engineering to society than first-year classes. Higher mean journal quality for a class (C_JQCode), more experienced teachers (T_NYT), and participating in an extra engineering unit (T_Civil) also predict more positive interests and attitudes among students in the class, though they don't affect gender bias. At the school level, schools with more students receiving free or reduced-price lunch (O_FRL) have students with more positive Aspirations and Enjoyment, but less positive attitudes about Value to Society and less decrease in Gender Bias.

Discussion

We analyzed data from the EIA survey to answer three questions: first, do engineering interests and attitudes change after an engineering curriculum intervention? Second, are there treatment differences in interests and attitudes after participation in an engineering unit? And third, are there demographic differences that predict differences in engineering interests and outcomes? The answer to all questions is yes. All students regardless of treatment self-report that they become more positive in their interests and attitudes, and express less gender bias, after engineering. However, the type of relationship is different for our measure of gender bias than for interest in engineering, aspirations to be an engineer, enjoyment, or value of engineering.

Students engaging in EiE, our treatment curriculum, show less gender bias after participating in engineering than students in the E4C control group. We cannot definitively say why this is the case, but some differences between the curricula suggest possible reasons. EiE uses a narrative, fictional story to introduce the field of engineering and the design challenge, with deliberate inclusion of a diversity of characters, including female engineers and children learning engineering. E4C uses nonfiction prose to explain the field of engineering and the design challenge, without any particular people featured; it is possible that the featuring of diverse examples of engineers in EiE stories helps to lessen gender bias about engineers and engineering.

Students participating in the EiE treatment express the same value of engineering to themselves and society as the control group. In terms of their interest in engineering in school, aspirations to become an engineer, and enjoyment of engineering, however, these are lower than the control group. Again, we do not have data to explain this difference; however we may hypothesize that the greater complexity and challenge of EiE may have something to do with it—qualitative data and analysis would be required to further investigate the reasons behind these differences.

Students participating in the second year of the study, as well as students from classes that implemented the extra-dose civil engineering unit, students with more experienced teachers, and students from classes with higher journal quality overall, all tended to express less gender bias and more positive attitudes, suggesting that more experience with engineering, and having teachers with more experience and higher quality teaching in their class, all tend to improve students' perceptions of gender equity in engineering, as well as their interest in and attitudes towards engineering.

For demographic differences, we see that female students tend to express less gender bias and more positive interests and attitudes than others after engineering, as do students with more books at home, and students who complete more of their journals. Black students however tend to express more gender bias than other students, and less positive interest and attitudes. This suggests a need for more careful and higher-quality intervention in particular with minority students.

Future Work

Our results hint at the influences on student interest in, attitudes towards, and gender bias regarding engineering, but thus far we can only definitively describe what differences exist. To further understand what affects student interest and attitudes, we intend to undertake more detailed quantitative analysis, as well as qualitative research making use of video data and student interviews. At this time, we are preparing to impute missing data, and use Hierarchical Linear Modeling (HLM) to better apportion variance among the student, class, and school levels and improve predictions. We also have collected a large corpus of video data and student interviews for the E4 study, which we are examining for further insights.

Contributions to science education and to NARST

With engineering now part of the NGSS, teachers, curriculum developers, and researchers have reason to explore the impact of engineering education on students' attitudes toward and interest in engineering. An understanding of how student, teacher, and school demographics, as well as details of implementation of engineering curriculum, can affect students' interests, attitudes, and gender bias can help educators and curriculum developers to design educational interventions that can have a positive impact on students, and possibly on their future educational trajectories.

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