Argument-driven Engineering in Middle School Science Classrooms: The Study of Engineering Attitudes and Efforts to Broaden Engineering Participation by Exposing All Students to Multiple Engineering Design Tasks (RTP, Diversity)

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Argument Driven Engineering in Middle School Science Classrooms: A Growth Curve Model Analysis of Engineering Attitudes
(RTP, Diversity)

Abstract

The goal of this study was to examine how the use of a newly developed instructional model is related to changes in middle school students' attitudes toward engineering and participation in engineering careers. Although the literature shows that much has already been implemented in the way of promoting equity in engineering and science, this study uniquely takes place in the context of a science classroom where middle school students propose, support, critique, and revise engineering design solutions, and it helps to elucidates how their attitudes toward engineering change as familiarity with the design process grows. Four prototype engineering design tasks were developed using the argument driven engineering (ADE) framework by the research team to allow students to engage in engineering design by incorporating disciplinary core ideas and math principles, use evidence-based argumentations to develop and critique design solutions, and participate in collaborative and individual learning through writing and discourse. The ADE framework was implemented in two middle schools in a southern state of the U.S. with two teachers and a total of over 100 students. Surveys were administered at three time points, scoring students on three attitudinal factors: *Engineering Self-Identity*, *Engineering Interest*, and perceptions of *Engineers' Benefit to Societ*y. Student engineering interest and perception of engineers' benefit to society were both found to decrease on average from one survey to the next, while scores on engineering self-identity stayed the same on average. Additionally, not knowing an engineer was shown to be associated with a disadvantage in the factors of both interest in engineering and perceptions of engineers' benefit to society. The limitations of the study include a small number of time points, a lack of a control group, minimal collection of open-ended data, and software limitations.

Introduction

The addition of both engineering design and practices in the *Next Generation Science Standards (NGSS)* [1] has provided an opportunity for the development of curricula and new instructional frameworks that integrates engineering into science classrooms. The development of such curricula and frameworks has been the call of many K-12 science education panels and committees [2], [3], including the *Teachers Advisory Council,* who proposed five benefits of adding engineering in K-12 classrooms: 1) an increased learning in math and science, 2) an awareness of the work of engineers, 3) the ability to engage in engineering design, 4) increased interest in pursuing an engineering career, and 5) improved technological literacy [4]. With these goals in mind, the objective of this study was to examine how a newly developed instructional model, known as Argument Driven Engineering (ADE), is related to changes in middle school students' attitudes toward engineering and participation in engineering careers. This study of engineering attitudes is important both for developing effective curriculum and pedagogy for engineering in science classrooms, and also for addressing nation-wide problems with diverse representation and participation in engineering degree programs and occupations.

In 2012 the President's Council of Advisors on Science and Technology issued a report projecting that to meet future workforce needs in the next decade, the U.S. must increase the number of undergraduate STEM degrees from current rates by about 34% each year; furthermore, that women and underrepresented minorities who make up 70% of college students only make up around 45% of STEM degrees, representing a large potential source of STEM professionals [5], [6]. Such underrepresented groups, along with ethnic minorities, ought to be a priority in those being brought into the STEM field, especially since they are projected to account for over 50% of the U.S. population by the year 2043 [7].

This trend of underrepresentation in STEM fields has been attributed to factors such as lack of financial resources, a lack of role models, and academic unpreparedness [8], [9], [10]. However, factors such as self-efficacy have been suggested as having a link to attaining a STEM degree among underrepresented minorities [11], [12], [13]. Self-efficacy is related to a person's belief in their ability to succeed in a behavior or task, the amount of effort they put into the task, and their persistence in the task despite obstacles [14]. Self-efficacy is something learned from experiences of accomplishments, observations of others' successes, and ones' persuasion of one's ability to succeed [15]. Career choices can be facilitated by strong self-efficacy beliefs [11], [16], [17].

Additionally, the factor of engineering identity plays a role in a student's choice of a career in engineering [27] along with student persistence and retention in the field [28], [29]. Godwin [30] dissociates identity into three separate factors: recognition from others, interest in engineering, and performance/competence, which is tied closely with self-efficacy. Similar measures are thus used in the survey instrument for this work. Also tied to engineering interest is the exposure of students to seeing the ways in which engineers contribute to society, how they change the world, and how they make it a better place. Explicitly showing this can help encourage future engineering interest and broaden participation in the field [31].

The literature shows that much has already been implemented in the way of promoting equity in engineering and science. Much of what has been done has been in the form of engineering courses, after school programs, engineering curriculum with science content included, and other forms of standalone curricula. Well-known examples include Project Lead the Way, Engineering is Elementary, Learning by Design, Engineering Your World, and the Infinity Project [18]. Impacts of similar curricula have been documented even in recent submissions to this publication. Yilmaz, et al. [19] looked at the impact of a hands-on summer camp on student attitudes towards engineering, and found that the quality and diversity of activities affects program effectiveness. Danforth et al. [11] used a summer outreach program and found that interest in attending the school the program was associated with increased engineering attitudes and knowledge as demonstrated by self-made knowledge assessment questions. Baldwin, et al. [20] developed an engineering design course that met for ten Saturdays for two hours per week, both in middle school and in high school classes. This course introduced students to the engineering design process and focused on the development of "teamwork, problem solving, and verbal communication skills" (p.2). The course involved five design projects to select from, incorporating research component and design criteria and constraints. They, along with Mangold, et al. [21] showed that the engineering design process can be effective for introduction of STEM concepts in K-12. Lachapelle and Cunningham [22] used a project-based learning engineering curriculum for their treatment condition, and their results showed that students participating in an engineering curriculum had higher enjoyment, desire to learn, and valuation of engineering than those who did not participate.

ADE takes a new approach and is different from what is generally seen in the literature in that the framework fits within a two-week period – not a semester as similar inquiries do – and this framework places a unique emphasis on argumentation and writing. ADE was prototyped and based on the Argument Driven Instruction (ADI) model, and thus is designed to make lab experience more authentic through multiple Science and Engineering Practices (SEPs), enabling students to construct, critique, and refine ideas. ADE emphasizes the use of science and math skills in student engineering design and evidence-based decision-making [23]. By taking place within a two-week timeline, the ADE framework takes into account teacher concerns regarding time and resources. Furthermore, it engages students in critical thinking, oral and written discourse, and evidence-based decision-making with the goal of seeing whether a focus on argumentation in the engineering design process helps students participate in NGSS engineering practices. This focus addresses the use of evidence-based design in engineering, and because of the instructional model's design, it optimizes the likelihood of widespread adoption, given teacher and classroom limitations, and thus maximizes student learning of engineering. ADE is also unique in that it is intentionally developed to be an instructional model and not a specific curriculum. As an instructional model, it can be used as a template for other curriculum developers, which is important since teachers tend to adapt curriculum apart from research-based principles [24], [25], [26]. Thus, this model ideally allows for greater fidelity of implementation.

This study of ADE-use in the classroom contributes to the current base of knowledge in that it takes place in the context of a science classroom in which middle school students propose, support, critique, and revise engineering design solutions, and it elucidates how their attitudes toward engineering change as familiarity with the design process grows. The research question then is: How does participation in an ADE instructional framework within the confines of a science classroom affect students' perceptions, interest, and identity in engineering over time?

ADE Overview

The ADE model serves as a template for teachers to develop new engineering design tasks (EDTs) that are compatible with middle school science courses. EDTs are a sequence of activities that allow students to engage in engineering design by incorporating DCIs and math principles, use evidence-based argumentations to develop and critique design solutions, and participate in collaborative and individual learning through writing and discourse.

Four prototype EDTs were developed using the ADE framework by the research team. The purpose of these prototypes was to identify revisions for the framework as well as student challenges regarding engineering practices. The four EDTs include *Developing a Passive Vaccine Storage Device*, *Developing a Hand Warmer for Homeless Individuals, Developing a Highway Crash Safety Barrier*, and *Developing a Biodiversity Monitoring Device*. Table 1 below lists each EDT along with the NGSS DCIs and engineering standards covered by each.

Table 1: Description of the four EDTs.

Engineering Design Task (EDT)	**Performance Expectations (PEs)**	**Disciplinary Core Ideas (DCIs)**	**Science and Engineering Practices (SEPs)**

Developing a Passive Vaccine Storage Device	MS-PS3-3: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer	Energy is spontaneously transferred out of hotter region or objects and into colder ones	• Designing solutions
			  ○ Undertake a design project to construct a solution that meets specific needs and constraints.
			  ○ Evaluate potential designs based on prioritized criteria
			• Planning and carrying out investigations
			  ○ Plan an investigation and identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed.

Developing a Hand Warmer for Homeless Individuals	MS-PS1-6: Undertake a design project to construct, test, and modify, a devise that either releases or absorbs thermal energy by chemical processes	Some chemical reactions release energy, others absorb and store energy	• Analyzing and interpreting data
			  ○ Apply concepts of statistics to analyze and use graphical displays to characterize trends or relationships in data.
			• Designing solutions
			  ○ Optimize performance of a design by prioritizing criteria, making tradeoffs and revising a design.
			• Engaging in an argument from evidence
			  ○ Make a written argument that supports the performance of a device based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.

Developing a Highway Crash Safety Barrier	MS-PS2-1: Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects	For any pair of interacting objects, the forces exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction	• Designing solutions
			  ○ Undertake a design project to construct a solution that meets specific needs and constraints.
			• Planning and carrying out investigations
			  ○ Evaluate potential designs based on prioritized criteria
			  ○ Plan an investigation and identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed.

Developing a Biodiversity	MS-LS2-5: Evaluate competing	Biodiversity describes the variety of	• Analyzing and interpreting data ○ Apply concepts of statistics to analyze and use graphical displays to

Monitoring Device	design solutions for maintaining biodiversity and ecosystem services	species found in Earth's terrestrial and oceanic ecosystems**.** The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health	characterize trends or relationships in data.
			• Designing solutions
			  ○ Optimize performance of a design by prioritizing criteria, making tradeoffs and revising a design.
			• Engaging in an argument from evidence
			  ○ Make a written argument that supports the performance of a device based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.

Each EDT consists of eight stages (See Table 2): *introducing the problem, concept generation, concept selection, design argumentation, design testing, evaluation argumentation, report development, and reflection and discussion.* Essentially the entire process each EDT involves active student engagement in science and engineering practices. Depending on teacher implementation (e.g., number of design iterations), each EDT takes 300-400 minutes to complete.

Table 2: EDT stages.

EDT Stage	General Components
Introducing the problem	• Provide design challenge • Identify needs and constraints
Concept generation	• Research the problem • Generate concepts
Concept selection	• Determine criteria for evaluation • Concept evaluation
Design argumentation	• Concept design argument • Critique and feedback
Design testing	• Iterations of the design • Testing and evaluation
Evaluation argumentation	• Design evaluation argument • Critique and feedback
Report development	• Written report • Critique and feedback
Reflection and discussion	• Reflect on product and process • Develop plans for future work

Program Implementation

The ADE framework was implemented in two middle schools in a southern state of the U.S. These two schools were selected because of a pre-existing relationship between the researchers and the school district. The district recommended working with the selected schools because both the principals and the teachers were generally receptive to implementing novel instructional practices. One of the two middle schools from which the data used for this study were collected is located in a city with a population of just over 100,000. It has an enrollment of over 1,000 combined seventh and eighth grade students. The student body is 39% Hispanic, 37% White, 14% African American, and 5% Asian. In this school, 32% are eligible for free or reduced-price lunch, and 8.5% of the students are English Language Learners. Property tax rates in the city in which the school is located are one of the lowest in the region, and has been ranked as one of the safest cities with a population of 100,000 or more in the U.S. for over 10 years. It is located near a large metropolitan city known for being a major hi-tech center.

Two teachers at the school agreed to participate in the study. One teacher is a middle-aged African American woman has been a teacher at the school for three years and had previously worked as a researcher in a science industry. The other teacher is a middle-aged Caucasian male who has taught for over twenty years in a private school previous to working at this current school. Over 100 students in total from both teachers assented and received parental consent to participating in this study. As of this study, the students have participated in three EDTs: *Developing a Passive Vaccine Storage Device*, *Developing Hand Warmers for Homeless Individuals, and Developing a Highway Crash Safety Barrier.*

Methods

The survey instrument used for this study was adopted from the items developed by Godwin [30] for the measurement of science identity. The three latent constructs tested in the original scale were recognition (e.g., "My parents see me as an engineer"; Cronbach's alpha = 0.77), interest (e.g., "I am interested in learning more about engineering"; Cronbach's alpha = 0.89), and performance/competence (e.g., "I am confident that I can understand engineering in class"; Cronbach's alpha = 0.88). The author reported good model fit via overall fit indices (CFI = 0.96; TLI = 0.95; RMSEA = 0.077).

The surveys were administered at three time points: before students started the first EDT, before the second EDT, and after finishing the second EDT. Although teachers were asked to give surveys as soon as possible after finishing an EDT, surveys were generally administered within two weeks of EDT completion. This implementation may have partially addressed any student recency bias, i.e., the impacts of student perceived success or failure on EDTs. The period of time between Survey 1 and 2 was eight weeks, and the time between Surveys 2 and 3 was twelve weeks. (The issue of unequal spacing of measurements is addressed by the use of growth curve modeling, which includes *time* as a predictor variable at Level 1.) The purpose of this was to capture a baseline measure and the change over time of the attitudinal factors of interest to the study. The survey questions can be seen in Table 3. It uses a seven-point anchored scale, with questions that are matched across all survey administrations. Some alterations to the language of Godwin's original questions were made in order to make the questions more general and appropriate for middle school students, and a few questions were added in order to fit the theoretical framework, for testing of additional student attitude constructs surrounding societal contributions of engineers and engineering identity in a more general sense. The increase in the scale size from the original five-points to seven-points was to allow for greater potential measurement of change across time. To support this grouping of items, an exploratory factor analysis was performed and is described later.

All students who took the survey were exposed to the ADE framework and participated in the EDTs in their classes. No control group was used since the focus of this study was to see growth and changes in attitudes over time in general. However, students were asked to respond to questions regarding certain demographics that could be used to disaggregate the data in analyses.

Table 3: Engineering attitudes survey instrument.

Construct	*To what extent do you agree or disagree with the following statements?*									
Identity	a. My family sees me as an engineer.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	b. My teacher sees me as an engineer.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	c. My friends see me as an engineer.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
Interest / Self efficacy	d. I want to learn more about engineering.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	e. I enjoy engineering.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	f. I see myself pursuing a career in engineering.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	g. I am good at engineering.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	h. I can overcome setbacks in engineering.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
Societal contributions	i. Engineers work to improve society.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	j. Engineers have contributed greatly to fixing the world's problems.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree
	k. Engineers are important in solving society's problems.	Strongly Disagree	0	1	2	3	4	5	6	Strongly Agree

Survey responses were collected from 103 students. However, data from only 75 students were analyzed because of a constraint of the Hierarchical Linear Modeling program (HLM7), which requires student identification to be sorted equally at both levels of analysis. Since only 75 students responded to demographic data questions to be used as explanatory variables at the upper student level, the same number of unique student identifications must be used at the lower level of analysis. Student demographics can be seen in Table 4.

Table 4: Frequencies of student demographics.

Sex

	Frequency	Percent
Male	37	49.3
Female	38	50.7
Total	75	100.0

Ethnicity

	Frequency	Percent	Valid Percent
White	29	38.7	38.7
Hispanic/Latino	22	29.3	29.3
Black/African American	5	6.7	6.7
Native American/American Indian	1	1.3	1.3
Asian/Pacific Islander	8	10.7	10.7
Other	9	12.0	12.0
Multiple	1	1.3	1.3
Total	75	100.0	100.0

Know an Engineer

	Frequency	Percent	Valid Percent
Yes	34	45.3	45.3
No	41	54.7	54.7
Total	75	100.0	100.0

Responses on the survey were scored from 0-6, with 0 representing Strongly Disagree, and 6 Strongly Agree. Mean scores across all students were used to summarize responses on each survey. Mean responses scores by each item are shown in Table 5. During the administration of Survey 2, the last three items (i-k) were omitted during printing. As a result, only two surveys, Survey 1 and Survey 3 contain responses for those items.

Table 5: Frequencies of responses by survey items.

	Survey Items	Survey 1			Survey 2			Survey 3		
		Mean	N	SD	Mean	N	SD	Mean	N	SD
a	My family sees me as an engineer.	2.73	74	1.80	2.78	72	2.00	2.83	75	1.85
b	My teacher sees me as an engineer.	2.50	72	1.38	2.69	72	1.74	2.53	75	1.66
c	My friends see me as an engineer.	2.01	74	1.85	1.90	72	1.86	1.85	75	1.84
d	I want to learn more about engineering.	4.14	74	1.83	3.49	72	1.99	3.23	75	1.98
e	I enjoy engineering.	3.71	75	1.92	3.46	72	1.92	3.25	75	1.89
f	I see myself pursuing a career in engineering.	2.54	74	2.01	2.31	72	2.07	2.45	75	1.93
g	I am good at engineering.	2.87	75	1.63	2.86	70	1.82	2.95	75	1.81

h	I can overcome setbacks in engineering.	3.14	72	1.88	2.80	70	1.82	3.00	74	1.73
i	Engineers work to improve society.	5.29	75	1.05	n/a	n/a	n/a	4.63	75	1.49
j	Engineers have contributed greatly to fixing the world's problems.	5.16	75	1.18	n/a	n/a	n/a	4.58	75	1.51
k	Engineers are important in solving society's problems.	5.00	75	1.25	n/a	n/a	n/a	4.50	74	1.50

Prior to the main analysis, an exploratory factor analysis (EFA) was conducted for these 11 items (using scores from Survey 1) to combine related items and create composite scores. The purpose was to confirm the constructs under which these items factored in the original measurement tool [30], and also to better understand how the latent constructs underlying the items were indeed impacted by the addition of new items and exclusion of certain others from the original tool. The advantage of using an EFA is that it can reduce the Type 1 error rate associated with a high number of statistical tests, and it also increases analytical power for detecting statistically significant differences. Through the use of an EFA, we can see which sets of items appear to be measuring the same factor.

The extraction method used was principal axis factoring with a direct oblimin rotation. The pattern matrix resulting from using an eigenvalue cutoff of one was a 2-factor solution. Because the scree plot showed that increasing the number of factors could also be a good fit for the data, the analysis was rerun, this time forcing a 3-factor solution, in an attempt to match the number of factors mentioned in the theoretical framework. In the 3-factor solution, items *g* and *h* factored under separate factors, while in the original tool, they both were contained within the same factor, namely that relating to Performance/Competence. Furthermore, the alteration of these items from the context of the original tool led the researchers to make the decision to exclude them from the analyses. As a result, the EFA was rerun with the same settings, forcing a 3-factor solution, but excluding items *g* and *h*. Of these three factors, each consisted of three items loading on that factor with no cross-loadings. These three factors are made up of 9 of the 11 items and were named *Engineering Self-Identity*, *Engineering Interest*, and *Engineers' Benefit to Society* (See Table 6). The composite score for each factor was calculated by averaging students' scores across all items on that factor. These three composite scores were used as the dependent variable in the main analyses. Definitions of each factor are given below.

Engineering Self-Identity – A measure of the degree to which students identify themselves and perceive their family, teacher, and friends as recognizing them as an engineer. Higher scores on this factor indicated a greater sense of Self-Identity as an engineer

Engineering Interest – A measure of the degree to which students find interest in doing engineering. Higher scores on this measure indicate greater degrees of Interest in engineering.

Engineers' Benefit to Society – A measure of the degree to which students believe that engineers contribute to society by changing the world and make it a better place. Higher scores on this measure indicate greater degrees of students' belief in Engineers' Benefit to Society.

Table 6: Survey items comprising the factors of interest.

Factor	Cronbach's Alpha	Mean	Survey Items
1: Engineering Self-Identity	.823	2.43	My family sees me as an engineer. My teacher sees me as an engineer. My friends see me as an engineer.
2: Engineering Interest	.896	3.18	I want to learn more about engineering. I enjoy engineering. I see myself pursuing a career in engineering.
3: Engineers' Benefit to Society	.912	4.87	Engineers work to improve society. Engineers have contributed greatly to fixing the world's problems. Engineers are important in solving society's problems.

Results

The goal of the analysis was to identify how students' attitudes toward engineering changed over time, specifically on the factors of Engineering Self-Identity, Engineering Interest, and perception of Engineers' Benefit to Society. A growth curve analysis was selected to accomplish this objective, as it addresses the effect of individual variables on the status of outcomes at time = 0 (defined by the researcher) as well as on the growth curve. A hierarchical linear modeling (HLM) approach to the growth curve analysis was used for a number of reasons: 1) It allows for unequal time intervals and nonsynchronous measurement of repeated measures and 2) in cases of outcome missingness, it does not employ listwise deletion (e.g., if data for at least one repeated measure are provided, they are used) [32]. The issues surrounding parametric analyses of Likert-type data are addressed by the use of summarized ratings using means and standard deviations of Likert scales rather than individual Likert questions [42], and furthermore, the robustness of Pearson correlations and regression have been demonstrated in regards to issues of skewness and non-normality of Likert ratings [43].

Student survey data were input into SPSS as two separate SPSS files, one for each level of analysis. Level 1 data is comprised of repeated measures, which are within-persons occasions, with *time* being the only predictor. Level 2 data includes the student-level predictors which in this study included gender, coded as *Female* (dummy coded Male = 0, Female = 1); *Ethnicity*, which included White, Hispanic/Latino, Black/African American, Native American/American Indian, Asian/Pacific Islander, Other, and Multiple, but was recoded as *Ethnicity_rec*, dummy coded as 0 = White, 1 = all other ethnicities (Asian/Pacific Islander was originally grouped with White as a minority group over-represented in Engineering [33], however, because the label included both Asian and Pacific Islander and the literature has shown the Asian label to be problematic [34], [35], the decision was made to keep Asian/Pacific Islander in a separate grouping); and *Knowing an Engineer*, coded as 0 = Knows an Engineer, 1 = Does Not Know an Engineer. The *time* variable was recoded (*time_rec*) such that the repeated measures coded Survey 1 = -2, Survey 2 = -1, and Survey 3 = 0. This way, the interpretation of the coefficient interpreted as the expected outcome score when time = 0 would represent time at Survey 3.

The program used for the analysis was the HLM7 student version, the main constraint of which is a limit on the number of Level 2 explanatory variables to three. The three predictors listed above were chosen as a result of some exploratory analyses to see which predictors would yield the greatest explanation of outcome variance in the population. A new MDM file was created, selecting for a longitudinal data structure. Level 1 and Level 2 specifications used the SPSS data for package input, and Missing Data was allowed at Level 1, to delete missing data when making an mdm file. The variables chosen at Level 1 included Student IDs (recoded as integers from 1-75), *time_rec*, *SelfIdentity*, *Interest,* and *Engineer_Benefit*, and the variables chosen at Level 2 included the same recoded Student IDs, as well as *Female*, *Ethnicity_rec*, and *KnowEngineer*.

Engineering Self-Identity

An unconditional model for *SelfIdentiy* was first set up. The outcome variable was *SelfIdentity*, and *time_rec* was added as the predictor, uncentered. The residual (r_1) was selected to allow growth rate to vary across persons. The models were as follows:

Level 1: $SELFIDEN_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + r_{1i}$

After looking at graphs of all student cases, the functional form, though varying, seemed to be linear. Thus, a linear functional was determined to be most fitting. Analysis of the unconditional model yielded the following results, shown in Table 7.

Table 7: Output from unconditional model with *SelfIdentity* as outcome.
Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	2.401665	0.179933	13.348	74	<0.001
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	-0.020009	0.076269	-0.262	74	0.794

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	1.44904	2.09971	74	504.11310	<0.001
TIMEREC slope, r_1	0.47103	0.22187	74	149.28698	<0.001
level-1, e	0.65538	0.42952			

From the results shown in Table 7, on average, Engineering Self-Identity score at Survey 3 (β_{00}) was 2.40. The *t* test result suggests that this Self-Identity score is different from zero in the population (p < .001). The change in Engineering Self-Identity from one survey to the next (β_{10}) was not different from zero in the population (t = -.262, p = .794). The variance in Self-Identity score at Survey 3 is 2.01. The statistical test result suggests that the Self-Identity score at the third survey differs across students in the population (χ^2 = 504.113, p < .001). The variance in Engineering Self-Identity growth rate is .22. The statistical test result suggests that Self-Identity growth rates vary across students in the population (χ^2 = 149.287, p < .001).

Because variance in Engineering Self-Identity scores at the Survey 3 and the growth rate varied across students in the population, a conditional model was set up in an attempt to explain this variance with predictors. In the Level 2 equations, *Female*, *KnowEngineer*, and *Ethnicity_rec* were added as explanatory variables, all uncentered. The models were as follows:

Level 1: $SELFIDEN_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(FEMALE_i) + \beta_{02}*(KNOWENGI_i) + \beta_{03}*(Ethnicity\_rec_i) + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + \beta_{11}*(FEMALE_i) + \beta_{12}*(KNOWENGI_i) + \beta_{13}*(Ethnicity\_rec_i) + r_{1i}$

Analysis of the conditional model yielded the following results, shown in Table 8.

Table 8: Output of conditional model with *SelfIdentity* as outcome.

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	t-ratio	Approx. $d.f.$	p-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	3.499801	0.281495	12.433	71	<0.001
FEMALE, β_{01}	-1.078700	0.329806	-3.271	71	0.002
KNOWENGI, β_{02}	-0.670530	0.337726	-1.985	71	0.051
ETHNICITY, β_{03}	-0.364344	0.318505	-1.144	71	0.256
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	0.100759	0.140953	0.715	71	0.477
FEMALE, β_{11}	-0.203289	0.139940	-1.453	71	0.151
KNOWENGI, β_{12}	-0.025805	0.144145	-0.179	71	0.858
ETHNICITY, β_{13}	-0.007475	0.153644	-0.049	71	0.961

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	$d.f.$	χ^2	p-value
INTRCPT1, r_0	1.26524	1.60084	71	383.66386	<0.001
TIMEREC slope, r_1	0.47820	0.22868	71	145.45708	<0.001
level-1, e	0.65571	0.42996			

From the results in Table 8, it can be seen that holding knowing an engineer and ethnicity constant, females have a Self-Identity score that is 1.08 points less than that of males at Survey 3 (β_{01}). This relationship between gender and Self-Identity is statistically significant (t = -3.721, p = .002). After including *Female*, *KnowEngineer*, and *Ethnicity_rec* in the model, the variance remaining in Engineering Self-Identity score is 1.60. The statistical test result suggests that variance still remains in the population (χ^2 = 383.664, p < .001). After including these explanatory variables in the model, the variance remaining in the growth rates is .23. The statistical test result suggests that variance in the growth rates remains in the population, after including *Gender*, *KnowEngineer*, and *Ethnicity_rec* (χ^2 = 145.457, p < .001).

Engineering Interest

Next, an unconditional model for *Interest* was set up. The outcome variable was changed to *Interest*. The models were as follows:

Level 1: $INTEREST_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + r_{1i}$

Looking at graphs of all student cases, the functional form seemed to be linear. Thus, a linear functional was determined to be most fitting. Analysis of the unconditional model yielded the following results, shown in Table 9.

Table 9: Output from unconditional model with *Interest* as outcome.

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	2.932369	0.201879	14.525	74	<0.001
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	-0.254970	0.083696	-3.046	74	0.003

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	1.59350	2.53925	74	412.46226	<0.001
TIMEREC slope, r_1	0.43927	0.19296	74	116.93767	0.001
level-1, e	0.81503	0.66427			

From the results shown in Table 9, on average, students decrease in Engineering Interest by .26 points from one survey to the next (β_{10}). This decrease is greater than zero in the population (t = -3.046 p = .003). The variance in Interest score at Survey 3 is 2.54. The statistical test result suggests that the Interest score at the third survey differs across students in the population (χ^2 = 412.462, p < .001). The variance in Engineering Interest growth rate is .19. The statistical test result suggests that Interest growth rates do vary across students in the population (χ^2 = 116.938 p = .001).

Because variance in Engineering Interest scores at the Survey 3 and in Engineering Interest growth rates varied across students in the population, a conditional model was set up in an attempt to explain this variance with predictors. In the Level 2 equations, *Female*, *KnowEngineer*, and *Ethnicity_rec* were added as explanatory variables, all uncentered. The models were as follows:

Level 1: $INTEREST_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(FEMALE_i) + \beta_{02}*(KNOWENGI_i) + \beta_{03}*(Ethnicity\_rec_i) + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + \beta_{11}*(FEMALE_i) + \beta_{12}*(KNOWENGI_i) + \beta_{13}*(Ethnicity\_rec_i) + r_{1i}$

Analysis of the conditional model yielded the following results, shown in Table 10.

Table 10: Output of conditional model with *Interest* as outcome.

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	3.993434	0.303322	13.166	71	<0.001
FEMALE, β_{01}	-1.316922	0.339111	-3.883	71	<0.001
KNOWENGI, β_{02}	-1.158818	0.341000	-3.398	71	0.001
ETHNICITY, β_{03}	0.473667	0.345035	1.373	71	0.174
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	-0.145462	0.145130	-1.002	71	0.320
FEMALE, β_{11}	-0.195760	0.148384	-1.319	71	0.191
KNOWENGI, β_{12}	-0.236698	0.144711	-1.636	71	0.106
ETHNICITY, β_{13}	0.236035	0.156249	1.511	71	0.135

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	1.31573	1.73114	71	292.31654	<0.001
TIMEREC slope, r_1	0.42297	0.17890	71	109.23262	0.003
level-1, e	0.81591	0.66571			

From the results in Table 10, it can be seen that holding constant ethnicity and knowing an engineer, engineering interest among females is less than males by 1.32 points at Survey 3 (β_{01}). This relationship between gender and interest is statistically significant (t = -3.883, p < .001). Holding gender and ethnicity constant, students who do not know an engineer have an interest score of 1.16 points less than students who do know an engineer at Survey 3 (β_{02}). This relationship between knowing an engineer and interest score is statistically significant (t = -3.398, p = .001). After including gender, knowing an engineer, and ethnicity in the model, the variance remaining in engineering interest score is 1.316. The statistical test result suggests that variance still remains in the population (χ^2 = 292.317, p < .001). After including these explanatory variables, the variance remaining in engineering interest growth rate is .179, with variance still remaining in the population (χ^2 = 109.233, p = .003).

Engineers' Benefit to Society

Finally, an unconditional model for *Engineer_Benefit* was set up. The outcome variable in the models was changed to *Engineer_Benefit*. The models were as follows:

Level 1: $ENGINEER\_BENEFIT_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + r_{1i}$

Looking at graphs of all student cases, the functional form seemed to be linear. Thus, a linear functional was determined to be most fitting. Analysis of the unconditional model yielded the following results, shown in Table 11.

Table 11: Output from unconditional model with *Engineer_Benefit* as outcome.
Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	4.595556	0.160652	28.606	74	<0.001
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	-0.281110	0.082497	-3.408	74	0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	1.31608	1.73208	73	627.93993	<0.001
TIMEREC slope, r_1	0.63223	0.39971	73	328.45820	<0.001
level-1, e	0.47940	0.22982			

From the results shown in Table 11, on average, students decrease in their perception that Engineers Benefit Society by .28 points from one survey to the next, i.e., Survey 1 to Survey 3, since Survey 2 was missing (β_{10}). This decrease is greater than zero in the population (t = -3.408, p = .001). The variance in Engineers' Benefit score at Survey 3 is 1.73. The statistical test result suggests that the Engineers' Benefit score at the third survey differs across students in the population (χ^2 = 627.940, p < .001). The variance in perception of Engineers' Benefit to Society growth rate is .40. The statistical test result suggests that growth rates in perception of Engineers' Benefit to society vary across students in the population (χ^2 = 328.458, p < .001).

Because variance in Engineers' Benefit to Society scores at the Survey 3 and growth rates in student perceptions of Engineers' Benefit varied across students in the population, a conditional model was set up in an attempt to explain this variance with predictors. In the Level 2 equations, *Female*, *KnowEngineer*, and *Ethnicity_rec* were added as explanatory variables, all uncentered. The models were as follows:

Level 1: $ENGINEER\_BENEFIT_{ti} = \pi_{0i} + \pi_{1i}*(TIMEREC_{ti}) + e_{ti}$
Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(FEMALE_i) + \beta_{02}*(KNOWENGI_i) + \beta_{03}*(Ethnicity\_rec) + r_{0i}$
Level 2: $\pi_{1i} = \beta_{10} + \beta_{11}*(FEMALE_i) + \beta_{12}*(KNOWENGI_i) + \beta_{13}*(Ethnicity\_rec) + r_{1i}$

Analysis of the conditional model yielded the following results, shown in Table 13.

Table 12: Output of conditional model with *Engineer_Benefit* as outcome.

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	5.265341	0.223037	23.608	71	<0.001
FEMALE, β_{01}	-0.514716	0.290097	-1.774	71	0.080
KNOWENGI, β_{02}	-0.671163	0.288975	-2.323	71	0.023
ETHNICITY, β_{03}	-0.083079	0.300418	-0.277	71	0.783
For TIMEREC slope, π_1					
INTRCPT2, β_{10}	-0.042393	0.124378	-0.341	71	0.734
FEMALE, β_{11}	-0.105496	0.142781	-0.739	71	0.462
KNOWENGI, β_{12}	-0.262294	0.128096	-2.048	71	0.044
ETHNICITY, β_{13}	-0.085044	0.144533	-0.588	71	0.558

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	1.25265	1.56912	70	542.96539	<0.001
TIMEREC slope, r_1	0.62466	0.39020	70	304.51574	<0.001
level-1, *e*	0.48428	0.23453			

From the results in Table 12, it can be seen that holding constant gender and ethnicity, scores of Engineers' Benefit to Society for students who do not know an engineer is less than for students who do know an engineer by .67 points at Survey 3 (β_{02}). This relationship between knowing an engineer and perceptions of Engineers' Benefit to Society is statistically significant ($t = -2.323$, $p = .023$). Holding gender and ethnicity constant, students who do not know an engineer increase in their perceptions of Engineers' Benefit to Society by .26 points less from one survey to the next than students who know an engineer (β_{12}). This decrease in growth rate is statistically significant ($t = -2.048$, $p = .044$). It is important to again note that Survey 2 did not include questions on this factor, thus only data from Surveys 1 and 3 are included. After including *Female*, *KnowEngineer*, and *Ethnicty_rec* in the model, the variance remaining in perceptions of Engineers' Benefit to Society score is 1.57. The statistical test result suggests that variance still remains in the population ($\chi^2 = 542.965$, $p < .001$). After including these explanatory variables in the model, the variance remaining in growth rates is .39. The statistical test result suggests that variance in the growth rates remains in the population, after including gender, knowing an engineer, and ethnicity (($\chi^2 = 304.516$, $p < .001$).

Discussion

The results from these analyses were comprised of both expected findings along with several unexpected and unintuitive findings. The finding that female students have lower scores than male students in both Engineering Self-Identity and Interest at Survey 3 is not too surprising, as the need to support interest in engineering degrees and careers despite gender differences is well-documented in the literature [36], [37], [38], [39]. Without the use of a control group, it is difficult to know whether this decrease in Identity and Interest is different for students who had not been exposed to the ADE framework nor participated in the EDTs. However, this finding does further emphasize the need to better support girls in their interest in Math, Science, and Engineering.

This point is made even clearer by the more unexpected finding of significant student decrease in engineering interest on average from one survey to the next. This is paired with a decrease in students' perception that engineers benefit society from one survey to the next. Given the effort to expose students to engineering and the explicit inclusion within the ADE framework of ways in which engineers and engineering helps to improve society and make the world a better place, we expected student attitudes on these factors to improve or at the very least remain unchanged [31]. Significant variances in the mean and slopes of these scores were found to remain even with the inclusion of explanatory variables (*Female*, *Ethnicity_rec*, and *KnowEngineer*). A host of other potential factors will likely explain these variances in the population, and the use of a non-student, full version of HLM7 would provide the analytical power to include more than three predictor variables concurrently and may help to better explain these findings. Anecdotal reports from classroom observations and speaking to the teachers involved in the study point to an issue of fidelity of implementation. One teacher explicitly stated that they had determined after the first EDT to cut out the section of the framework that has students write about and discuss the potential benefit of the task for addressing societal needs (e.g., the benefit of designing hand warmers for the homeless in the city in which the students live and go to school). Such changes make student attitudinal growth difficult to analyze. However, implementation fidelity of the framework is something that will be an area of focus in future studies.

Another explanation for the decrease in engineering interest and the perception of the benefit of engineering to society over the time of the three surveys is that the EDTs which students were asked to complete were rigorous and difficult. For example, for the design task "Developing a Biodiversity Monitoring Device," in some of the classes at one of the schools, not one group of students was successful in accomplishing the design challenge within the constraints of the task. For this specific task, the research team has already made plans for improving the feasibility of the challenge for the future. However, this points to another possible reason for the findings and to a research challenge in general: the very presence of engineering standards in the middle school science classroom. In another paper resulting from this study, the tensions which science teachers express with teaching engineering during the school year are explored, namely with difficulties reconciling the amount of time the design tasks take to complete, along with the lack of overlap of the engineering standards and those tested on state exams which are a high priority for the schools in the state in which they teach. Furthermore, given that the use of the ADE framework seems to be one of the first or early attempts in the literature to integrate engineering directly into the middle school science classroom, there does not seem to be much research into the appropriateness or fit of engineering in middle school science standards. Instead, classroom-based practices seem to be more intentionally integrated into undergraduate lecture halls [40].

The matter of teacher expertise may also explain the observed changes in students attitudes, as neither of the teachers in the study have a degree or professional experience in an engineering field. A possible result is that instruction and guidance of students through the design tasks may not have facilitated the engagement of student interest or encouragement of students through difficult aspects of the challenges. However, interestingly, while interest in engineering decreased over time, student attitude scores on engineering self-identity stayed the same, on average (2.40 at Survey 3). Thus, while student attitudes toward wanting to learn more about engineering, toward their enjoyment of engineering, and toward their thoughts of pursuing an engineering career decreased over the period of these three surveys, their perception of family, teacher, and friends seeing them as an engineer remained unchanged. While the hope, undoubtedly, is that both interest in engineering and identity of students as engineers will increase, the unique and novel exposure to rigorous engineering design tasks within the context of their middle school science classrooms may perhaps lead to a more accurate assessment and appreciation of future coursework and experience in engineering. For students who had a successful personal experience with the EDTs, their sense of preparedness for work in engineering may have grown stronger. However, the research team will need to work to find ways of better supporting students who may not have felt as successful in order foster the same sense of preparedness across all students, especially for girls and minorities. Regardless, it is clear that much work needs to be done to have engineering thoughtfully integrated into the science classroom; simply inserting it into a set of standards is not enough.

Other findings from the analyses point to the benefit of knowing an engineer on engineering attitudes and interest, which has also been documented in the literature [41]. Not knowing an engineer is shown to be associated with a disadvantage in the factors of both interest in engineering and perceptions of engineers' benefit to society, namely average interest score by Survey 3, along with the average of and change over time in how students think of the benefit engineers have toward society. This may suggest that though all students may show a dip in their feelings of interest in engineering (over a period of about five months), perhaps as a result of exposure for the first time to an engineering framework that explicitly attempts to integrate engineering design, argumentation, and scientific core ideas, students who know an engineer and may have some idea of what the work of an engineer authentically looks like may see that the challenge "comes with the territory," and thus may not decrease in their interest or change in their perceptions of the benefits engineers have on society as much as their counterparts who do not have this personal connection outside of the classroom.

Conclusion

Analyses of student attitude survey data resulted in several findings, some of which were more or less expected based on the literature, and others which seemed more unintuitive given the components of the study and what has previously been written. By Survey 3, students on average decreased in their Engineering Self-Identity, Engineering Interest, and perceptions of Engineers' Benefit to Society scores. Female students had lower scores by Survey 3 than male students in Self-Identity and Interest scores. Furthermore, students who did not know an engineer were shown to have a disadvantage in Interest and perceptions of Engineers' Benefit to Society at Survey 3, and they decreased in these perceptions at a higher rate than students who did know an engineer.

This study faced a number of limitations, including a small number of time points (3), a lack of a control group, minimal collection of open-ended data, and software limitations. Looking ahead, each of these issues will be addressed in future studies. For example, we plan to collect data over a greater number of time points, giving the students the space to "rebound" from any changes in attitudes linked to not being accustomed to the framework. We hope to improve the validity of our findings by performing a confirmatory factor analysis of the current survey tool. We also have plans to include a control group in additional studies in order to look directly at the impact of student exposure to the ADE framework. Finally, open-ended survey items will be included and themed to increase the robustness of quantitative findings.

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