Factors Influential to Fourth Graders Engineering Learning and Identity Development

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Introduction

Elementary engineering education reform does not happen in isolation of school, classroom, and student level contexts. Many factors, both related and unrelated to teacher professional development will likely influence students' achievement of engineering. While most of the literature concerning the effectiveness of teacher professional development focuses on the quality of the professional development program, [1, 2, 3] there are contextual differences that can lead to differing outcomes between schools within the same school district, and even teachers within the same school[4]; author et al., under review. Furthermore, small studies focused on one or two variables associated with student learning are limited and may have confounding variables that are unaccounted for by the model. Therefore, there is a need to comprehensively examine what contextual factors and mediators influence students' learning of engineering and which are not significant.

The purpose of this research is to understand the relationship of the following hypothesized influences on fourth grade students' learning of engineering and engineering identity development: (a) school socio-economic status, (b) teacher experience with engineering, (c) student gender, (d) student race/ethnicity, and (e) student prior exposure to engineering.

Literature Review

In recent years, much work has been devoted to the synthesis of the large body of teacher professional development literature [1, 2, 3, 5, 6, 7, 8]. Desimone[3] goes further to identify the model that has been formed over years of TPD research, shown in Figure 1. There is a consensus that the critical features of TPD can be expected to increase teacher knowledge and skills, improve their practices, and then have potential to influence student achievement. The critical features are foundational and interactive with teacher knowledge, attitudes, and beliefs. Teacher knowledge, skills, attitudes, and beliefs have a reciprocal relationship with how teachers change their instruction. In other words, a change in knowledge, skill, attitudes, and beliefs will lead to a change in instruction. Also, changing instruction will lead to changes in knowledge, skills, attitudes, and beliefs. Changes in instructional practice have also a reciprocal relationship with student learning. All of these changes occur within unique contexts of teacher and student characteristics, curriculum, school leadership, and the larger policy environment.

Desimone (2009) not only synthesized empirical evidence to identify the critical features of a TPD program, but also proposed a core theory of action model.[3] The critical features Desimone identifies are: (1) content focus (2) active learning, (3) coherence, (4) duration, and (5) collective participation. Figure 1 describes the core theory of action model proposed by Desimone[3]. In essence, the core theory behind teacher professional development is that by providing high quality teacher training, students will improve in their learning.

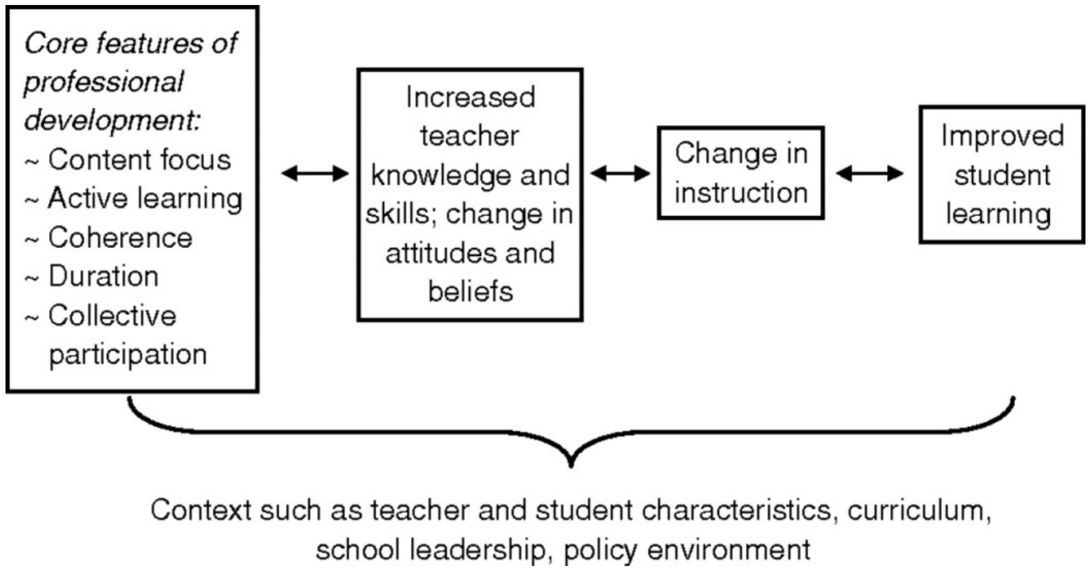

Figure 1. Desimone Core Theory of Action for Teacher Professional Development

Desimone L M EDUCATIONAL RESEARCHER 2009;38:181-199

Contexts such as teacher and student characteristics are understood to have a role in the student outcomes, yet are not fully specified in Desimone's model. Yoon, Diefes-Dux, and Strobel[9] proposed a modification to traditional TPD evaluation models [10,11] in which context is more directly added to the model. Teacher characteristics are hypothesized to have direct effects on teacher satisfaction, knowledge, and perceptions, which then influence teaching practice, and student knowledge and perceptions. Student characteristics are hypothesized to have direct effects on student knowledge and perceptions. School characteristics are hypothesized to have influence on both teacher and student knowledge and perceptions, as well as how teachers teach. Little is known about which "contextual variables" are most significant and how TPD can seek to intervene at the contextual level.

While elementary teachers that participate in professional development for engineering vary in terms of teaching experience and developmental level, the majority are completely new to engineering, if not also new to the pedagogical approaches that are particularly appropriate for engineering (e.g. open-ended problems, problem-based learning, inquiry, hands-on group activities, etc). Other researchers have noted that inquiry and project based learning challenge teachers' existing capabilities and requires significant professional development.[12, 13] In a similar manner, the engineering design process also challenges teachers' capabilities, as well as their formerly held understandings or misunderstandings about engineering. Time is needed for teachers to get comfortable with engineering and teaching engineering. Previous research found teachers were more comfortable with the engineering lessons in the second year of implementation.[14] In addition, in a correlational longitudinal study, students' whose teacher had more than one year of experience teaching engineering, on average, had significantly larger engineering learning gains[15].

Engineering has historically been stereotyped as a white male profession, and men continue to be the majority of working engineers.[16] We hypothesize that teacher gender may be a contextual variable that contributes to teacher knowledge and perceptions about engineering, whereas student gender and socioeconomic status are also hypothesized to be directly related to student perceptions and knowledge of engineering.

Poverty continues to play a role in any school reform effort.[17] As part of a research synthesis, Berliner notes that poverty places severe limitations on educational reform. Therefore, we hypothesize that the school's classification as Title 1 or non-Title 1 would be directly related to the level of student achievement in engineering.

In a longitudinal study of elementary students in grades 2, 3, and 4,[18] found that students who had previous exposure to engineering lessons experienced significant cumulative gains in their knowledge of engineering. We therefore hypothesize that student previous exposure to engineering would be significantly related to student learning and perceptions of engineering.

Methods

Setting

This research was conducted as part of a large 5-year project, which provided teacher professional development to elementary teachers in grades 2-4, for the purpose of integrating engineering into their science lessons. The goal of the project was to provide high quality teacher professional development in engineering with ongoing support and then examine the impact on teacher change and student achievement. The focus of the professional development was for teachers to be able to: 1) convey a broad perspective of engineering, 2) articulate differences between engineering and science thinking, 3) develop a level of comfort in discussing engineers and engineering with elementary students, and 4) use problem-solving processes to engage in open-ended problem solving. An on-site teacher liaison provided ongoing support to teachers during the school year through brief workshops and individual consultation. Teachers were encouraged to collaborate with other teachers within the same school building and of the same grade level, when possible.

Each year, a new cohort of teachers committed to implementing engineering lessons for a minimum of two years. They attended a week-long academy where they learned about technology, the work of engineers, and the engineering design process. They were prepared to implement the following lessons: What is technology, What is engineering? Introduction to the engineering design process, and one *Engineering is Elementary* (*EiE*) unit[19], consisting of four lessons. After a year of implementation, teachers attended a three-day follow-up academy to answer questions and provide further support. Teachers had discretion over when they taught the lessons and to what extent they integrated engineering into their classroom beyond the given lessons.

Data collected in the last four years of the project were combined, which resulted in participation of 1,554 fourth grade students, their 47 teachers, and 14 schools. Teachers were asked to implement hands-on introductory lessons on technology and the engineering design process, in addition to one unit of Engineering is Elementary by the Museum of Science Boston[19].

Participants

While 1,554 fourth grade students and their 47 teachers from 14 schools participated in 5 year projects, only 1,025 students from their 44 teachers in 14 schools completed their demographic information and the pre- and post-surveys (described below). Table 1 shows characteristics of the students, teachers, and schools used in the data analysis for this study. As this project was 5 years long, 280 and 140 students had received the integrated engineering lessons once and twice prior to grade 4, respectively and 605 students were new to the engineering lessons when stated grade 4.

Table 1. Characteristics of students (n = 1,025), teachers (n = 44), and schools (n = 14)

Subject	Category	Subgroup	n	%
Student	Gender	Female	529	51.6
		Male	496	48.4
	Race/Ethnicity	American Indian or Alaskan	5	0.5
		Asian or Pacific Islander	101	9.9
		African American	213	20.8
		Hispanic	379	37.0
		White	322	31.4
		Multi-racial	5	0.5
	Prior Engineering Lessons	One year	674	65.8
		Two years	240	23.4
Teachers	Gender	Male	4	9.1
		Female	40	90.9
	Race/Ethnicity	African American	1	2.3
		Hispanic	6	13.6
		White	28	63.6
		No response	9	20.5
School	Title I Status	Yes	7	50.0
		No	7	50.0
	Location	Large City	11	78.6
		Urban Fringe	3	21.4

Note. Even though a school changed Title I status during the project period, the school was categorized as Title I school.

Measures

Student Knowledge Tests (SKTs). Student Knowledge Tests consist of items related to the science and engineering learning objectives of the lessons, with a total score between 0 and 15. The items were developed by a group of people including STEM faculty, research assistants, and elementary educators.[20] Dyehouse and colleagues reported a range for item difficulty from 0.20 to 0.81 when used as pre-test and from 0.30 to 0.90 when used as post-test. Similarly, the instrument presented a discrimination coefficient between 0.11 and 0.43 for the pre-test and between 0.25 and 0.52 for the post-test. In addition, a confirmatory factor analysis performed by the authors showed that all items loads were significant for measuring the same construct. Cronbach's α values were reported as 0.67 for the pre- and 0.79 for the post-test.

Engineering Identity Development Scale (EIDS). This survey consist of a Likert scale with 16 items related to students' self-beliefs. A confirmatory factor analysis performed by Capobianco, French, and Diefes-Dux[21] identified academic affiliation and engineering career as the two factors comprised by the survey. Scores ranged between 1 and 21 for the academic factor and a between 1 and 30 for the engineering factor. Capobianco et al. reported a Cronbach's α value of 0.76.

EIDS and SKTs were administered at the beginning and end of each school year.

Data Analyses

Prior to statistical analyses, assumptions for each statistical method were checked: independent observation, normal distribution, and equal variance. For the correlations among the variables of our interests, Pearson *r* correlation coefficients were obtained. All statistical results were evaluated with $\alpha = .05$ and their associated effect sizes reported.

After all inferential statistics, data were modeled in a path analysis using Mplus 7.0[22] Path analysis is a form of structural equation modeling that is more sophisticated than general linear regression, where several relationships between variables are allowed in one analysis.[23,24] Therefore, path analysis demonstrates direct and indirect relationships among the multiple variables. The initial path model was hypothesized on the basis of the literature review to explore associations among the observed variables, considering prior knowledge/identity as a mediator, as shown in Figure 1. Based on the fit indexes that Mplus 7.0 provides, the chi-square, root-mean-square error of approximation (RMSEA), comparative fit index (CFI), Tucker-Lewis index (TLI), and standardized root mean square residual (SRMR) were used to judge CFA model fits.[25]

Here, students' gender, prior engineering lesson experiences, teachers' gender and prior experience of teaching engineering lessons, and school Title I status, were considered as indicators of students' knowledge, academic and engineering identity. Based on an initial path model, several path models were constructed to test feasibility among associated variables by deleting non-significant paths after each modification of a model.

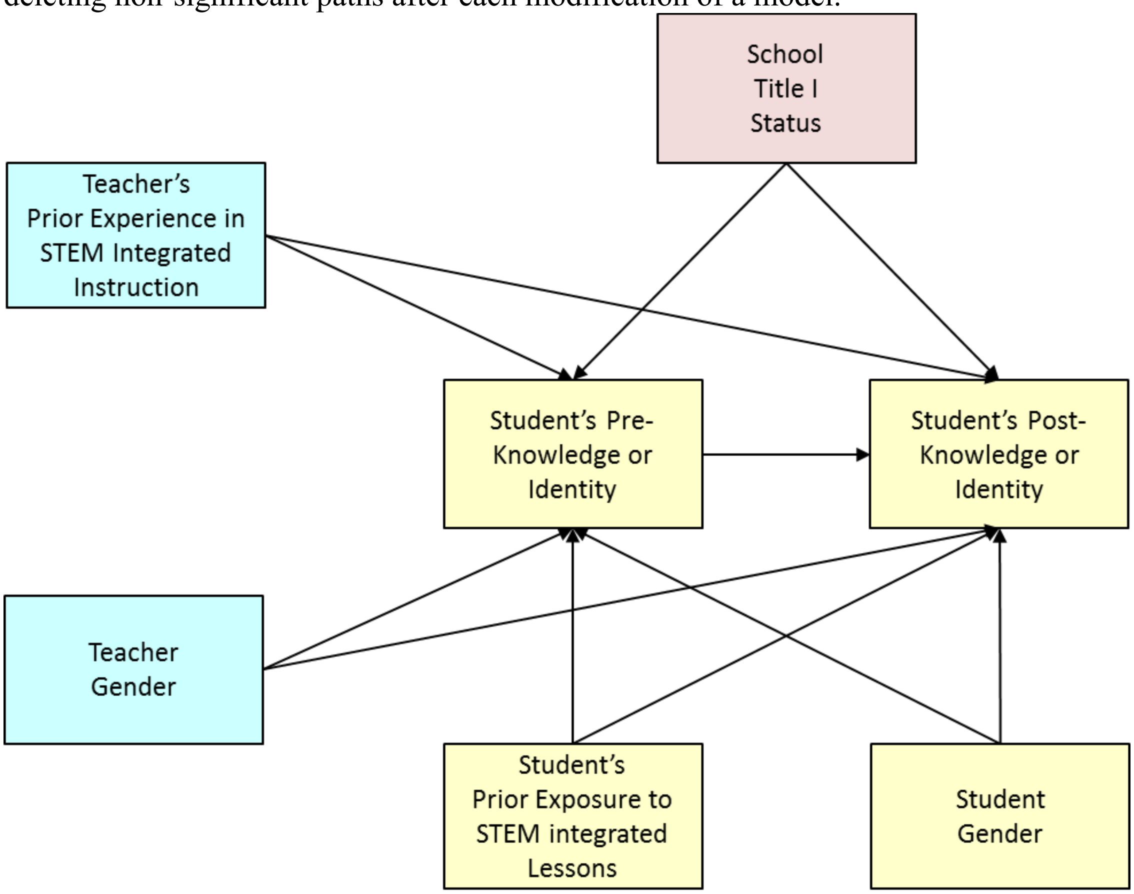

Figure 1. A hypothetical path model to test theoretical relationships among factors that may contribute to students′ engineering learning and Identity development

Results

Descriptive Statistics

Table 2 shows descriptive statistics of students' performance on the measures utilized this study as a whole and by subgroups in terms of gender and race/ethnicity. While there was no apparent changes between pre- and post-scores on the EIDS Academic scale, on average, students showed obvious increase in both EIDS Engineering scale and SKT scores.

Table 2. Descriptive Statistics on Students' Performance on the Measures by Subgroups

Category	EIDS Academic				EIDS Engineering				SKT			
	Pre-score		Post-score		Pre-score		Post-score		Pre-score		Post-score	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Female	18.03	2.04	18.22	2.16	23.21	3.24	24.66	2.79	6.88	2.84	9.31	3.27
Male	18.15	2.07	18.10	2.24	23.63	3.29	24.85	2.79	7.03	2.92	9.38	3.38
American Indian/Alaskan	19.00	1.58	18.60	1.34	21.80	1.64	23.60	2.70	8.40	2.97	8.80	5.26
Asian/ Pacific Islander	18.34	2.23	18.54	1.98	23.97	3.38	25.39	2.80	8.13	2.92	11.12	2.69
African American	17.93	2.17	18.16	2.31	23.15	3.44	24.76	2.76	6.50	2.84	9.05	3.44
Hispanic	17.99	1.93	17.94	2.04	23.43	3.32	24.64	2.88	6.20	2.56	8.50	3.21
White	18.22	2.04	18.29	2.36	23.39	3.06	24.65	2.68	7.74	2.94	9.99	3.19
Multi-racial	17.40	3.21	18.40	1.95	25.00	2.35	27.40	1.52	7.40	2.51	9.40	3.65
Total	18.09	2.05	18.16	2.20	23.41	3.27	24.75	2.79	6.96	2.88	9.35	3.32

Correlations

Pearson correlation coefficients were calculated between variables of our interests. Table 3 shows correlation coefficients between variables on student, teacher, and school characteristics, and students' identity development scale and knowledge test scores. Student gender was significantly correlated with the EIDS Engineering pre-scores but the correlation became non-significant on EIDS Engineering post-scores. Teacher gender was significantly correlated with student's SKT pre- and post-scores; the negative correlation indicates that students with a female teacher tended to perform better on the knowledge tests. Teachers' prior experience in STEM integrated instruction was significantly correlated with student's SKT pre- and post-scores. The positive correlation indicates that students with experienced teachers in STEM integrated instruction tended to perform better on the knowledge tests. School Title I status was significantly correlated with EIDS Academic pre- and post-scores and SKT pre- and post-scores: the correlations were all negative, implying that students in Title I schools tended to score lower than students in no Title I schools on both tests. When fourth grade students were exposed to the STEM integrated lessons in prior years (grade 2 or 3), they tended to have higher scores on both EIDS Engineering pre- and post-measures and SKT pre- and post-measures than students who didn't have the prior exposure. Both students' EIDS Academic and Engineering pre- and post-scores were significantly correlated with SKT pre- and post-scores.

Table 3. Correlations among Variables Utilized in the Study (n = 1,025)

	2	3	4	5	6	7	8	9	10	11
1. Student Gender	N/A	N/A	N/A	N/A	.026	.011	.029	-.027	.063*	.035
2. Student's exposure to STEM Integrated Lessons in Years	1	N/A	N/A	N/A	.184*	.075*	.022	-.001	.240*	.120**
3. Teacher Gender		1	N/A	N/A	-.107*	-.064*	-.012	-.047	.054	.002
4. Teacher's Prior Experience in STEM Integrated Instruction in Years			1	N/A	.106*	.065*	-.017	-.022	.124*	.050
5. School Title I Status				1	-.206*	-.285*	-.098*	-.089*	.030	.029
6. SKT Pre-score					1	.554*	.173*	.163*	.193*	.151*
7. SKT Post-score						1	.174*	.208*	.116*	.173*
8. EIDS Academic Pre-score							1	.412*	.195*	.118*
9. EIDS Academic Post-score								1	.053	.223*
10. EIDS Engineering Pre-score									1	.346*
11. EIDS Engineering Post-score										1

Note. N/A = Not applicable because of there is no expected correlation between two variables. Student gender (0 = female, 1 = male); Student Exposure to STEM integrated lessons in years = 0 ~ 3 years; Teacher gender (0 = female, 1 = male), Teachers' prior experience in STEM integrated instruction in years = 0 ~ 4 years; School Title I status (0 = no, 1 = yes); $^*p < .05$

SEM Results

Table 6 shows goodness-of fit indexes from the path models that we attempted based on the hypothetical path model to test theoretical relationships among factors that may contribute to students' STE knowledge and identity development as shown in Figure 1. Model 1 for each measure indicates a full model considering all the variables of our interests. Model 2 for each measure indicates the final model considering only significant variables and excluding non-significant variables, implying no relationship between variables. According to Brown' s [25] guide on fit indexes, all model fits were in good ranges: Chi-square values were not significant; the RMSEA was all in an acceptable range, which is defined as 0.08 or less; CFI and TLI were in a good-fit range, defined as 0.95 and over; and SRMR was close to 0.0, indicating an excellent fit.

Table 6. Path Models with Goodness-of Fit Indexes

	SKT		EIDS Academy		EIDS Engineering	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fit Indexes						

Chi-square	5.941	0.484	0.589	2.987	5.745	1.650
df	2	1	2	1	2	1
p	0.0513	0.4864	0.7449	0.0839	0.0566	0.1989
RMSEA	0.044	0.000	0.000	0.044	0.043	0.025
90% CI	(0.000, 0.087)	(0.000, 0.073)	(0.000, 0.043)	(0.000, 0.105)	(0.000, 0.086)	(0.000, 0.091)
CFI	0.992	1.000	1.000	0.990	0.981	0.997
TLI	0.957	1.005	1.039	0.970	0.894	0.990
SRMR	0.014	0.005	0.004	0.016	0.011	0.012
Variables						
Pre-score on						
Student Gender	$p = 0.588$	–	$p = 0.421$	–	$p = 0.153$	–
Student's Prior Engineering Lessons	$^{*}p < 0.001$	$^{*}p < 0.001$	$p = 0.452$	–	$^{*}p < 0.001$	$^{*}p < 0.001$
School Title I status	$^{*}p < 0.001$	$^{*}p < 0.001$	$^{*}p = 0.002$	$^{*}p = 0.002$	$p = 0.409$	–
Post-score on						
Pre-score	$^{*}p < 0.001$	$^{*}p < 0.001$	$^{*}p < 0.001$	$^{*}p < 0.001$	$^{*}p < 0.001$	$^{*}p < 0.001$
Student Gender	$p = 0.669$	–	$p = 0.149$	–	$p = 0.629$	–
Student's Prior Engineering Lessons	$p = 0.270$	–	$p = 0.895$	–	$p = 0.189$	–
Teacher Gender	$p = 0.082$	–	$p = 0.250$	–	$p = 0.432$	–
Teachers' Prior Experience in STEM Integrated Instruction	$p = 0.182$	–	$p = 0.614$	–	$p = 0.732$	–
School Title I status	$^{*}p < 0.001$	$^{*}p < 0.001$	$p = 0.164$	–	$p = 0.400$	–

Note. $^{*}p < 0.05$: RMSEA = root-mean-square error of approximation; CFI = comparative fit index; TLI = Tucker-Lewis index; SRMR = standardized root mean square residual

Engineering Learning. Figure 2 shows a path model on students' engineering learning. Students' pre-knowledge had the strong direct effect on student's post-knowledge. While students' prior exposure to STEM integrated lesson engineering had a direct effect on students' pre-engineering knowedge and a indirect effect on students' post- knowledge, school's Title I status showed both negative direct and indirect effects on students' post-knowledge. Interestingly, there were no signficant teacher effects on students' post-knowledge. In other words, regardless, teachers' gender and prior expereince in STEM integrated instruction, school Title I status and students' pre-knowledge were the most effective factors influecing students' post-knowledge. Table 7 shows the standardized magnitudes of indirect and direct effects of the significant variabes on students' post-engienering knowledge.

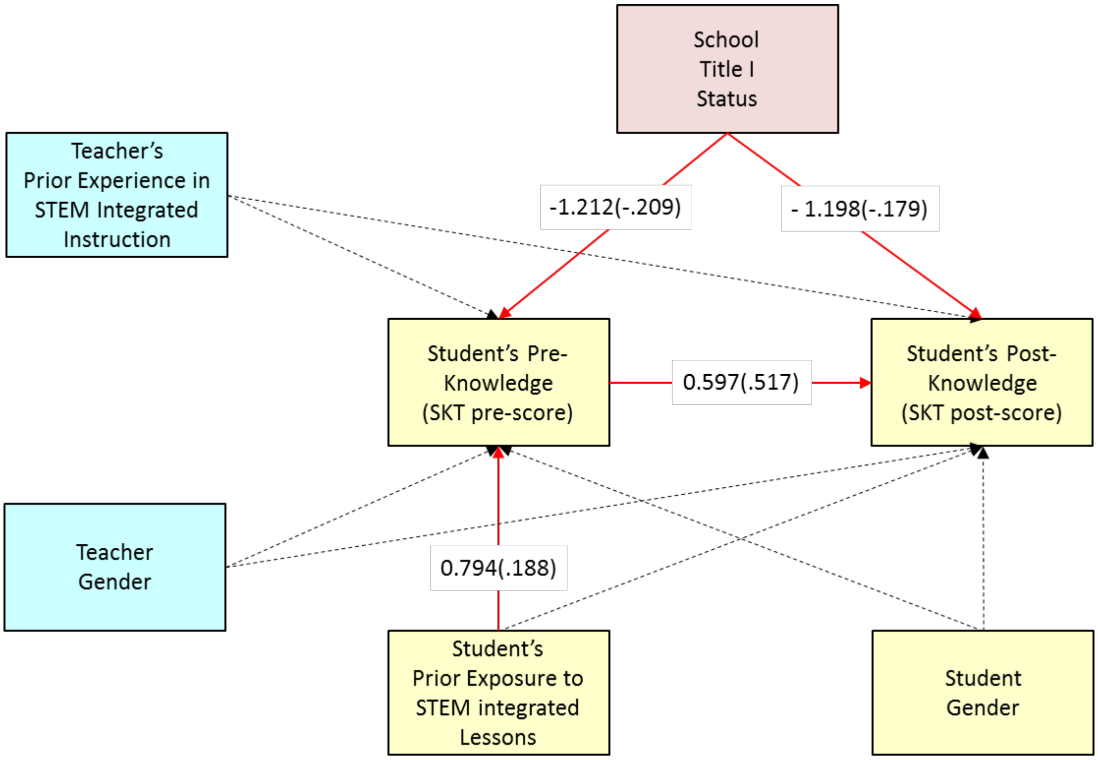

Figure 2. Unstandardized and standardized parameter (in parentheses) estimates from the final model on students'engineering learning (SKT scores).

Academic Identity Development. Figure 3 shows a path model on students' acadmic identity development. Students' pre-academic identity had the strong direct effect on student's post-academic identity. School Titl I status only showed a negative indirect effect on students' post-academic identity through students' pre-Academic identity. Interestingly, students' gender and prior-exposure to STEM integrated lessons as well as teacher characteristics (gender and prior expereince in STEM integrated instruction) were not influencing students' post academic-identity development. Table 7 shows the standardized magnitudes of indirect and direct effects of the significant variabes on students' post-academic identity development.

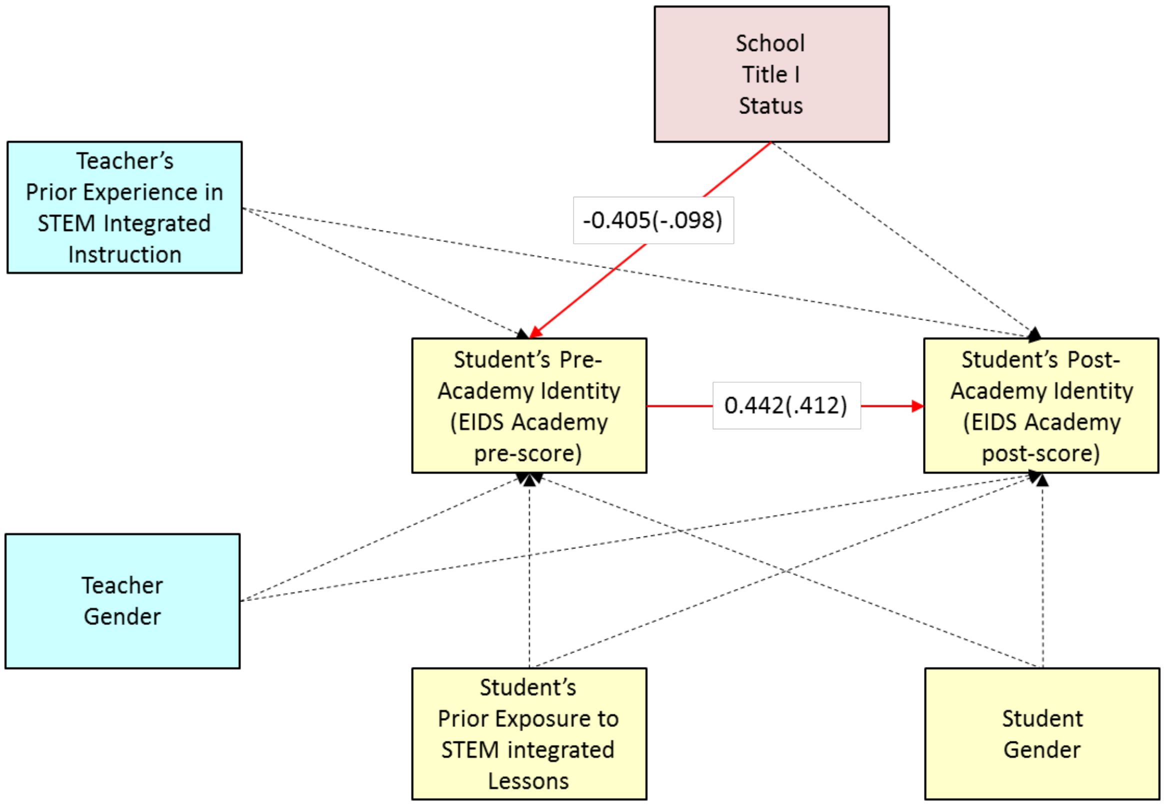

Figure 3. Unstandardized and standardized parameter (in parentheses) estimates from the final model on students' Academic Identity Development (EIDS Academic Scale scores).

Engineering Identity Development. Figure 4 shows a path model on students' engineering identity development. Similar to other path models discussed above, students' pre-engineering identity had the strong direct effect on student's post-engineering identity. Interestingly, the negative indirect effect of school Title I satatus was disappeared on students-post engineering identity. However, students' prior exposure to STEM integrated lessons appeared to have a positive indirect effect on students' post-engineering identity. Again, students' gender and teacher characteristics, such as gender and prior expereince in STEM integrated instruction, were not influencing students' post engineering identity. Table 7 shows the standardized magnitudes of indirect and direct effects of the significant variabes on students' post-engineering identity development.

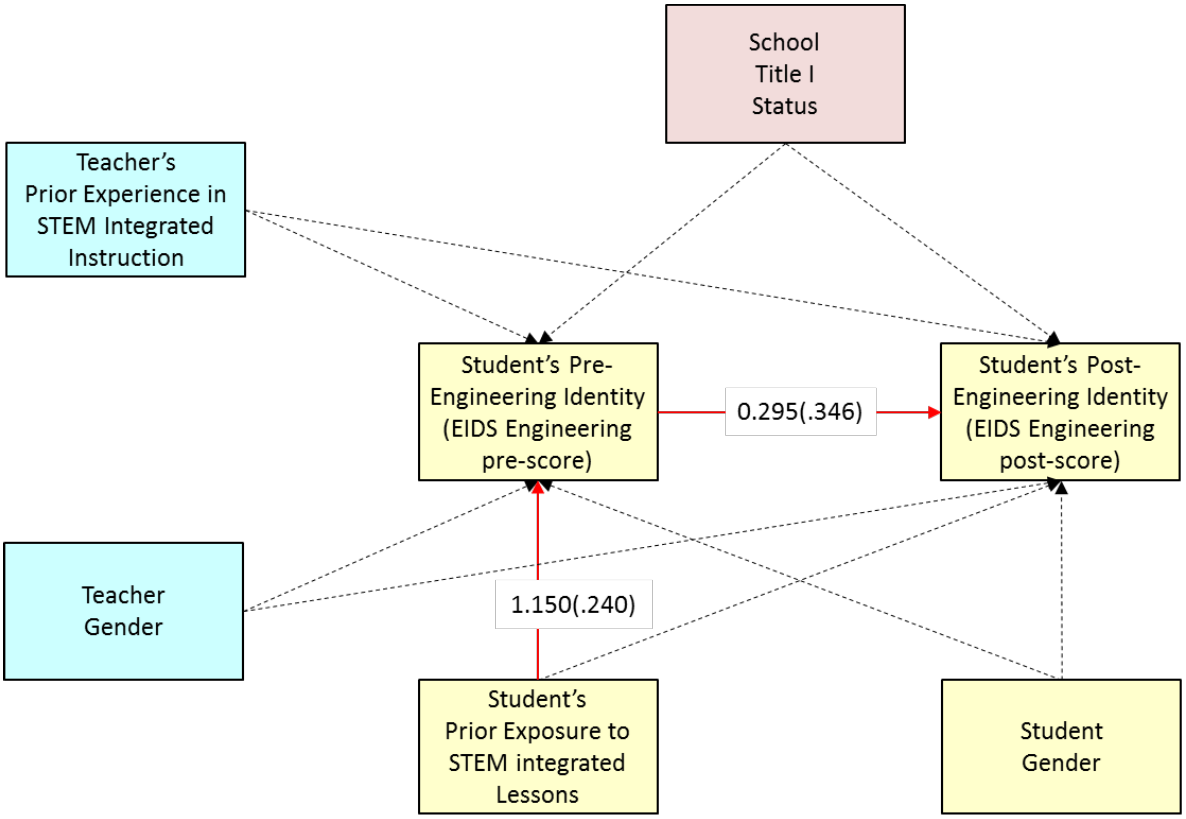

Figure 4. Unstandardized and standardized parameter (in parentheses) estimates from the final model on students' Engineering Identity Development (EIDS Engineering Scale scores).

Table 7 *Indirect and Direct Effects of Variables on Students' Learning*

Outcome	Variables	Direct	Indirect	Total
Students' Post-Knowledge	Students' Pre-Knowledge	0.517		0.517
	Students' Prior Exposure to STEM integrated lessons	–	0.097	0.097
	School Title I Status	-0.179	0.108	-0.071
Students' Post-Academic Identity	Students' Pre-Academic Identity	0.412	–	0.412
	School Title I Status	–	-0.040	-0.040
Students' Post-Engineering Identity	Students' Pre-Engineering Identity	0.346	–	0.346
	Students' Prior Exposure to STEM integrated lessons	–	0.083	0.083

Discussion

Path analysis allows the analysis of several variables in a single model, based on a hypothesized relationship. While smaller studies with less variables have shown a significant relationship between teacher and students experience with engineering (author et al., 2014), adding additional variables to the model, suggests that other relationships are more significant. In sum, path modeling indicates that the following relationships are significant, $p < 0.05$: (a) students attending lower socio-economic status schools (as identified by Title I status) have less learning gains in science and engineering than students attending no Title I schools, (b) students with prior exposure to engineering lessons have a greater increase in engineering identity development than students with no prior engineering exposure, and (c) while prior exposure to engineering led to significantly higher pretest scores on the knowledge test, there were no significant differences on students posttest scores. However, contrary to hypothesis, neither teacher nor student gender was significantly related to students knowledge or engineering identity development. In addition, teachers' experiences with teaching engineering, and students prior exposure to engineering lessons were not significantly related to student outcomes of knowledge and engineering identity development.

Conclusion

Engineering educational reform must consider the role of poverty in student learning. In this study, poverty is a more predictive variable of student learning gains than any other variable. In order to increase participation of under-represented minorities in engineering, direct effort must be made to understand how to support students in low economic schools to be successful in engineering. Future research should examine what additional barriers children in low socioeconomic schools face that hinder their achievement in engineering, compared with students who attend schools not given status as Title 1. Students in the current study were categorized according to their school status, not on the individual level. Future research may also consider whether there are variations within Title 1 schools based on parental socio-economic status, or whether these are school related factors.

As expected, prior exposure to engineering lessons was predictive of higher engineering identity development. This finding suggests that with ongoing exposure to engineering, students increase in their identity of themselves as the kind of person who could become an engineer. Elementary school is a time of career exploration and becoming acquainted with the world of work. As children are forming their ideas about what type of work they might like to do, it is important that they are aware of engineering and are open to future possibilities for themselves with engineering.

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