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The Effects of Pre-Engineering Studies on Mathematics and Science Achievement for High School Students*

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In this study, we examine the relationship between student enrollment in a pre-college engineering course, Project Lead The Way, and student achievement in science and mathematics. Using multiple regression analysis (N = 176), controlling for prior achievement, free/reduced lunch eligibility, and gender, students enrolled in PLTW courses performed marginally significant better in mathematics than those who did not enroll in the course at 0.10 alpha level. However, there is no significant relationship between PLTW course enrollment and student achievement in science. We discuss the implications for these findings and provide recommendations focusing on: making explicit integration between academic content and pre-engineering principles; developing assessments that adequately represent students' learning experiences in pre-college engineering; and examining the impact of student prior achievement and social backgrounds on students' later academic development and career opportunities in engineering.

Keywords: pre-engineering studies; mathematics achievement; science achievement

1. INTRODUCTION

IN EVERY INDUSTRIALIZED nation engineering serves as one of the primary vehicles for technological innovation, economic prosperity, national security, and advancements in public health. However, current educational trends in the U.S. portend a decline in these areas as the mathematical and scientific preparation of American K-12 students decline in relation to other industrialized nations, and US students opt out of engineering programs and careers. To address both the preparedness for and the appeal of college programs and future careers in engineering, federal mandates, such as the National Academy of Sciences' *Rising Above the Gathering Storm* [1] and recent amendments to the Carl D. Perkins Vocational Education Act, stipulate that vocational and academic education must be integrated. Substantial resources have been allocated 'to provide vocational education programs that integrate academic [math and science] and vocational education . . . so that students achieve both academic and occupational competencies.'[2]. To address this mandate, structured 'pre-engineering' education programs have emerged to provide hands-on, project-based curricula that focus on the explicit integration of college preparatory mathematics and science knowledge with engineering activities.

However, this is not an easy task. As Rose [3] points out, there is a fundamental challenge for Technical Education (TE): Public education institutions are responsible for both the intellectual growth and economic preparation of the youth in our society. On one hand, TE programs often lack a strong theoretical framework and a focus on the formal reasoning needed to facilitate generalization and life long learning in the face of rapid technological advancements, or to gain entry in demanding academic programs. On the other hand, general education programs often fall short in providing students adequate opportunities to apply the formal knowledge, emphasizing instead abstract descriptions and symbolic representations of observable phenomena [4]. Rather than resolving this paradox, the tendency in general education is to classify students into varying ability groups and project their career orientations toward college preparatory courses or career-oriented training [3]. While the potential for positive learning outcomes for students who experience the integration between formal education and TE is often discussed, little empirical evidence is available to assess the effectiveness of such integration. The current research explores the extent to which participating in these programs is successful at improving high school students' general math

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and science achievement. We focus on *Project Lead The Way* (PLTW) as an exemplar of the class of pre-college engineering programs that strives to implement the integration for TE and formal, college preparatory education.

1.1 Project lead the way

PLTW is one of the most widely used pre-college engineering programs in middle schools and high schools throughout the U.S. It is a multi-year, problem-based/project-based curriculum that has been adopted by over 1,400 schools (over 7% of all US high schools) in all 50 states and the District of Columbia [5, 6]. *PLTW* has two curricular programs. The *Gateway to Technology* program at the middle school level provides five nine-week courses for students in grades six through eight aimed at showing students how engineering skills, including those from math, science and technology, are used to solve everyday problems. The high school program, *Pathway to Engineering*™ offers three one-year foundation courses: *Introduction to Engineering Design, Principles of Engineering, and Digital Electronics*. Specialization courses such as *Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, and Computer Integrated Manufacturing,* as well as an engineering research capstone course entitled, *Engineering Design & Development* are also available. The *Pathway to Engineering*™ curriculum is designed to target students in secondary education who are aspiring to pursue postsecondary engineering studies.

In 2005 *PLTW* showed a significant pattern of growth, with 75% of the states reporting that they had already implemented the program, indicating an increased awareness and demand for the program and pre-college engineering courses [7]. Sander's investigation [8] indicates that 85% of all teachers who teach *PLTW* are TE teachers who have had TE teaching experiences. The *PLTW* curriculum extends beyond just course materials. Everyone teaching *PLTW* courses must attend a two-week professional development training provided by *PLTW*'s affiliated colleges and universities. The professional development training aims to make teachers proficient with the *PLTW* curriculum [5]. Professional training for high school guidance counselors is also available for participating schools. In addition to hosting summer training institutes and ongoing professional development, national affiliates offer graduate college credit opportunities for teachers.

According to the *PLTW* website, when combined with academic mathematics and science courses, *Pathway to Engineering*™ strives to introduce students to the scope, rigor and discipline of engineering and engineering technology [5]. Given the broad content embedded in *PLTW*, those students who do not intend to pursue further formal education can also benefit greatly from the technical knowledge and skills, as well as the logical thought processes, which result from enrolling in some or all of the courses provided in the curriculum. The NRC report [1], *Rising Above the Gathering Storm,* explicitly identifies *PLTW* as offering a model curriculum for providing rigorous K-12 content needed to improve math and science learning and increase America's technological talent pool.

As described above, *PLTW* is an appropriate choice of curriculum for our studies of the impact of pre-college engineering on student learning in science and math because of its widespread use, the extensive teacher training program, and the program's stated focus on integration engineering with science and mathematics. However, it is important to acknowledge that *PLTW* is only one program out of many for understanding impact of the curricular integration between TE and formal learning. We are aware that *PLTW* is unique in some respects, and fosters its own approach to teaching and learning. Therefore, any findings associated with *PLTW* cannot be immediately generalized to other TE programs, though they will contribute to our understanding of the complexities involved in pre-college engineering studies more generally.

1.2 Prior empirical research on pre-college engineering

Contemporary empirical studies have made noticeable contributions to the research involving pre-college engineering. One study found no significant differences by race or gender between TE participants and the current general student population [9]. Contrary to the general perception, the majority of TE concentrators (i.e., those taking three or more courses in a common career track) go on to college, not directly to work; 80% complete the same number of high school math and science course credits as their non-TE peers; and although TE concentrators as a group enter high school less well prepared than academic-only students, that gap is narrowed and may even be eliminated by the time they reach graduation [10, 11]. A number of studies examining career academies—college-preparatory curricula with career themes and established partnerships with community businesses—have shown that career academies enhance interpersonal social relations and engagement among teachers and students. However, these effects do not transfer to students' achievement on standardized tests, high school graduation rates, or higher educational attainment [12, 13]. The results of these studies suggest that the belief that TE students are different from those pursuing purely academic programs is unfounded.

Only recently have there been studies specifically directed at pre-college engineering curricula. In a report comparing student achievement and learning experiences between *PLTW* students and other TE students enrolled in the *High School That Works* (*HSTW*) network, Bottom and Uhn [14] found that *PLTW* students who completed at least three *PLTW* courses scored higher in math and science on the National Assessment of Educational Progress (NAEP), a set of national, standardized tests that contribute to the 'nation's report card' provided by the National Center of Educational Statistics, compared to other TE students in the *HSTW* network. According to this report, *PLTW* students in the sample were more likely than their *HSTW* counterparts to: complete four years of mathematics and three years of science courses; experience engaging instructional practices in their courses; integrate reading, math, and science knowledge into their TE courses; and perceive high school as an important preparation for their future. It is important to note that the sample of students in this study composed of 65% White, 22% African American, and 13% Other. A large proportion of the students' parents pursued post-secondary education (72%). Female students represent 14% of the sample. Because students were only sampled from the HSTW network and represented a specific demographic, these findings may not generalize to high schools more broadly.

However, a number of recent studies have found equivocal results. Our previous work on curriculum analysis specific to *PLTW* [15] revealed that the foundation courses provide very limited exposure to the mathematical content identified by the National Council of Teachers of Mathematics [16]. A much broader study of twenty-two pre-K–12 engineering curricula, including *PLTW*, produced similar findings [17]. These investigators bemoaned the prevalence of very basic mathematics and data gathering activities at the expense of more sophisticated and more relevant emphases on mathematical modeling and engineering design. The lack of emphasis on engineering preparation is also found in higher education. A recent Carnegie report [18] indicated that engineering schools, still heavily influenced by the academic traditions, are not preparing their students for the engineering profession which requires the acquisition of technical skills. Our subsequent analyses of the *PLTW* foundation curriculum showed that on the occasions when the mathematics concepts do arise, they are often implicitly embedded in the technology and tools of the course activities [19] rather than presented as pedagogical opportunities to explicitly integrate mathematical ideas into engineering contexts.

2. HYPOTHESES OF THE STUDY

Drawing on prior work in this area, we consider three major hypotheses to explain the possible outcomes resulting from the integration of math and science to pre-college engineering studies. First, because a pre-college engineering course like *PLTW* is an elective course, we assume that students enrolled in these courses will receive additional instruction and practice time in science and mathematics that are above and beyond that of the regular academic program. It follows that pre-college engineering course enrollment may be associated with higher levels of subject area-specific achievement. That is, students enrolled in *PLTW* courses could benefit more from the exposure of math and science content knowledge in an engineering context that is different from the academic courses taken by them and their non-*PLTW* peers. This leads us to our prediction that, controlling for prior achievement and other individual characteristics, students enrolled in *PLTW* courses are expected to demonstrate greater improvements in their achievement in mathematics and science compared to their non-*PLTW* peers. Following our previous work [20], we call this the *enriched integration hypothesis*. This hypothesis is supported by previous research indicating that the best predictor of achievement is time on task [21, 22]. Therefore, if the integration of science and math topics is effectively implemented, and if this integration can yield positive learning outcomes, then at a minimum, those taking *PLTW* courses should experience increased time spent learning mathematics and science, thus resulting in improvement in student achievement. This integration provides students with the opportunity to engage in hands-on and real-world projects, and make connections between the knowledge and skills taught in their academic math and sciences classes and their application to engineering projects. This comprehensive approach to instruction using collaborative, technology oriented, project-based activities enables students to synthesize and construct new knowledge in various contexts [23].

Two alternative hypotheses must also be considered. The *insufficient integration hypothesis* addresses the possibility that there may be little or no integration between math and science content knowledge and the engineering activities in *PLTW* courses. Even when there is integration, if it is done at a superficial level it may result in little or no impact on student learning. This hypothesis predicts that controlling for prior achievement and student characteristics, students enrolled in *PLTW* course will perform the same as their peers who do not enroll in these courses. Finally, it is important to acknowledge that pre-college engineering experiences have many unique qualities that are different from the typical math and science classroom. As such, the emphasis on collaborative design, engineering skills such as drafting, computer-aided design (CAD), measurement and fabrication may interfere with the analytical and abstract exercises that typically make up math and science assessments. The *adverse integration hypothesis* recognizes that interference from pre-college engineering could lead to changes in attitudes, confusion, or even misconceptions that hinder student performance. This hypothesis predicts that, controlling for prior achievement and student characteristics, students in *PLTW* courses will show lower science and mathematics achievement gains compared to students who are not enrolled in these courses.

Our recent study examined student math and science achievement (N = 140) as a function of *PLTW* enrollment for an ethnically and socioeconomically diverse school district (72% of families qualified for the Free/Reduced Lunch Program; 57% African American, 22% Hispanic, 12% White, 4% Asian, and 4% Other). We found that, while students generally gained in math and science achievement from 8th to 10th grade, students enrolled in *PLTW* foundation courses showed significantly smaller math gains than those in a matched group that did not enroll in *PLTW* courses [20]. We also found no measurable advantages on science assessments, after controlling for prior achievement, student characteristics, and teacher experience. We concluded that the data provided no support for what we termed the *enriched integration* hypothesis, which states that, after controlling for prior achievement and student characteristics, students taking one or more engineering courses will be expected to score higher on science and mathematics standardized tests than the students with no engineering coursework. Rather, we found the data most closely aligned with the *insufficient integration* hypothesis, in the case of science achievement, and the *adverse integration* hypothesis, for math achievement.

The results of our study mentioned above suggest not only a lack of integration between academic and pre-college engineering studies but also a deficiency in engineering experiences that are necessary to prepare students for future advanced studies and careers in engineering. When engineering experiences are put in place, results show mixed learning outcomes. The current study adds onto the existing body of research on the impact of pre-college engineering studies by investigating whether the results produced in previous studies can be replicated using a sample with different demographics—a school district with a higher socioeconomic population—thus expanding the generalizability of previous research and contributing to a richer understanding of the nature of engineering education at the high school level.

This study expands on our previous work on the effects of a pre-engineering curriculum on student achievement in science and mathematics [20] in the following ways: a) it uses different student demographics (larger proportion of students from higher social economic background); b) a random sampling technique is used to generate a comparison non-*PLTW* group; and c) multiple regression, rather than multi-level modeling, is used to estimate the relationship between *PLTW* and student achievement. It is important to note that because we did not randomly assign students to be in or out of these classes, causal claims are not supported by the current design and analysis techniques. However, the findings of this study will provide us with greater insights about pre-college engineering studies and factors that are associated with student achievement in science and mathematics.

3. METHOD

3.1 Sample

The current study reports findings from a sample of participants who are completely different from the participants analyzed in our previous investigation [20]. It consists of 176 eleventh-graders from four high schools in a moderately diverse urban school district in the Midwestern city with 30% students of color, 2% English Language Learners, 24% eligible for free/reduced lunch programs, and 15% identified for special education services. The students in this sample reside in an affluent community with median income for a family is around $60,000. Surrounded by a major university, 48.2% of city's population over the age of 25 holds at least a bachelor's degree. In recent years, *Forbes* magazine reported that the city has the highest percentage of individuals holding PhDs in the United States and having the lowest unemployment in the nation: 2.5%, less than half of the general U.S. population in 2004.

Using the school district information provided on course enrollment, the *PLTW* group was identified—those who enrolled in *PLTW* courses in the 2007-2008 academic year. This sample composed of 57 students enrolled in one or more *PLTW* courses offered and 119 students in the same grade level who did not enroll in *PLTW* courses in the 2007–2008 academic year. The non-*PLTW* group was identified using a random sampling technique generated by the statistical software SPSS where 119 students were randomly chosen to represent the students in non-*PLTW* group. Following the selection, cross-tabulation was implemented to summarize information pertaining to gender, ethnicity, free/reduced lunch, and special education. The *chi-square* procedure was used to test the null hypothesis that students in the *PLTW* group and those in the non-*PLTW* share similar characteristics with the alpha level set at 0.05. Overall, the results showed that–with the exception of gender ($p < 0.000$)–differences in free/reduced lunch eligibility ($p = 0.273$), special education status ($p = 0.575$), and English proficiency ($p = 0.749$) were not statistically different between *PLTW* students and their non-*PLTW* counterparts. The analysis above suggests that the random sampling was a success resulting in two groups with similar observable characteristics. Table 1 provides a description of the students in the sample.

3.2 Measures

Student achievement. Data on student achievement including 2005–06 and 2007–08 results from state standardized tests for the tenth-grade students in mathematics and science were provided by the school district. Both math and science

Table 1. Characteristics of the students in the sample

Enrollment	African American	Asian	Hispanic	White	Female	Special Education	Free/Reduced Lunch
PLTW (N = 57)							
Raw	6	8	2	41	9	10	1
(%)	(3.4)	(4.5)	(1.1)	(23.3)	(5.1)	(5.7)	(0.01)
Non-PLTW (N = 119)							
Raw	24	10	3	82	67	17	3
(%)	(13.6)	(5.7)	(1.7)	(46.6)	(38.1)	(9.7)	(1.7)

assessments were administered to students in November, 2005 (8th grade) and again in November, 2008 (10th grade). Using multiple-choice and short-answer questions, these standardized tests are designed to measure the state academic standards in mathematics and science. The scale scores for math range 350–730 for 8th grade and 410-750 for 10th grade. For science, the scale scores range 230–560 for 8th grade and 240–610 for 10th grade. The proficiency categories are advanced, proficient, basic, and minimal performance for all assessments.

Student background variables. The district also provided data on student characteristics including free/reduced-price lunch eligibility, and course enrollment. This information was used to construct a set of dummy variables for gender (female =1), free/reduced lunch (eligible = 1), and *PLTW* enrollment (students enrolled in at least one *PLTW* courses = 1). These variables, along with student prior achievement (2005-06 in 8th grade) in mathematics and science, were included as predictors in the regression analysis described in the following section. Table 2 provides descriptive statistics of the variables used in the analysis.

The table of descriptive statistics shows that the mean and standard deviation of 10th grade math achievement is 582.37 and 49.557 respectively, and for 10th science achievement it is 463.20 and 49.892 respectively. The mean (563.69) and standard deviation (47.058) for 8th grade math achievement is slightly lower. The same pattern is found for 8th grade science with a mean of 417.29 and standard deviation equals 48.463. Free/reduced lunch has a mean of 0.24, which implies that 24% of the sample is qualified for free/reduced lunch programs. The mean for female is 0.43, which indicates that 43% of the sample is female. Lastly, *PLTW* enrollment has a mean of 0.32, which represents 32% of the students in the sample enrolled in *PLTW* courses.

3.3 Analysis

First, correlation analyses were conducted to examine the relationship between student enrollment in *PLTW* courses and achievement in science and mathematics. Second, multiple regression techniques were used to examine the extent to which student characteristics—prior achievement (8th grade) on state standardized assessment, eligibility for free or reduced lunch programs (a measure of family socio-economic status), gender, and enrollment in one or more *PLTW* courses, as independent variables—would predict students' math and science achievement in the 10th grade. Third, standardized achievement scores were used to compare achievement test scores across grades and subject areas. The model is specified as:

$$Y_{\text{Achievement}} = \beta_0 + \beta_1 \text{ Prior Achievement} + \beta_2 \text{ Free/Reduced Lunch} + \beta_3 \text{ Female} + \beta_4 \text{ PLTW} + \varepsilon$$

Where Y (achievement), the dependent variable, is an estimate of student state standardized test score at 10th grade (in either math or science). The model also has four independent variables, or factors: prior achievement, a student's test score (in math or science) at 8th grade; free/reduced lunch status, a measure of family socio-economic status, with a value of 1 if a student is eligible for free/reduced lunch program, and 0 if not; female, with a 1 for females and 0 for males; and *PLTW* enrollment, with a 1 for those enrolled in one or more *PLTW* courses, and a 0 if not. β_0 represents the constant of the equation and is the estimated value of 10th grade student achievement (Y; typically the grand mean) when β_1, β_2, β_3, β_4 = 0 (i.e., as if we did not have any of the information obtained from knowing the values of the indepen-

Table 2. Descriptive statistics for student data (N = 176)

Variables	Minimum	Maximum	Mean	Std. Deviation
10th Grade Math Achievement	410	750	582.37	49.557
10th Grade Science Achievement	240	591	463.20	49.892
8th Grade Math Achievement	397	679	563.69	47.058
8th Grade Science Achievement	284	707	417.29	48.463
Free/Reduced Lunch	0	1	0.24	0.431
Female	0	1	0.43	0.497
PLTW Enrollment	0	1	0.32	0.469

dent variables for each student). β_1, β_2, β_3, β_4 are the slopes of the regression line, also known as the regression coefficients. Each regression coefficient tells us how much change we will see in Y (points students will increase/decrease in 10th grade achievement) for each unit change in the respective independent variable. This model represents achievement regressed on the prior achievement score, gender, free/reduced lunch status, *PLTW* enrollment, and the disturbance term (e), which captures the influence on student achievement of everything other than the independent variables specified in the equation.

4. RESULTS

Paired sample t-tests for the group as a whole (N = 176) indicate significant gains of student achievement in mathematics ($p < 0.01$) and science ($p < 0.01$) from 8th grade to 10th grade. Moderately high correlations (0.77 for math and 0.55 for science, respectively) between 8th grade and 10th grade achievement tests suggest that students who did well on their subject-specific test in 8th grade, tended to do well on the respective 10th grade test. Figures 1 and 2 provide a summary of the overall math and science achievement for 8th and 10th grades.

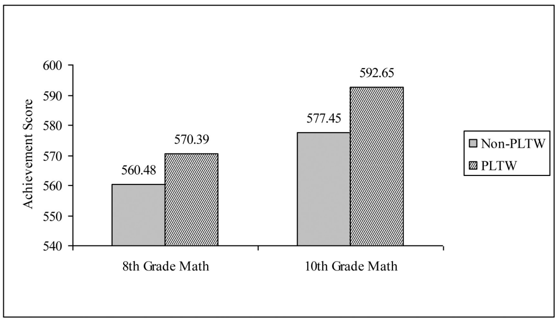

Fig. 1. Prior and current math achievement of *PLTW* and non-*PLTW* students.

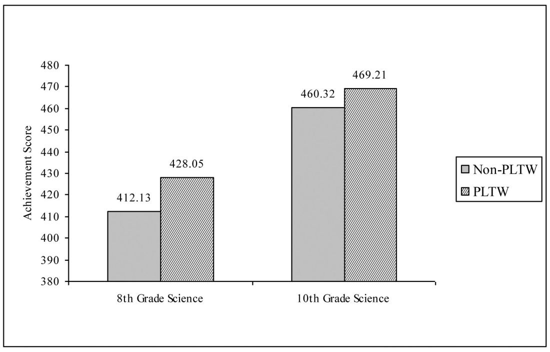

Fig. 2. Prior and current science achievement of *PLTW* and non-*PLTW* students.

Table 3, the correlation analysis between *PLTW* enrollment and math achievement, shows that these two factors were positively related: r = 0.14, *p* = 0.057. Another correlation analysis showed that *PLTW* enrollment and science achievement were positively related: r = 0.08, p = 0.270; however, this correlation is not statistically significant. We recognize that while the correlations between *PLTW* enrollment and student achievement are very low, based on previous research we have reason to suspect that statistical relationships can be found between these variables, once other factors are controlled for. Therefore, we proceeded with the subsequent analysis.

Regression analysis was used to examine the relationships among the variables. This technique is used to predict student achievement in mathematics and science given information about student prior achievement and other characteristics. Since the assessment scales may vary from year to year, it is necessary that we conduct subsequent analyses using standardized scores. A standard score is a transformed score that relates a raw score to the mean and standard deviation of the distribution. The standard score allows comparison of observations from different normal distributions. In this case, it enables us to compare the various types of outcomes related to mathematics and science achievements. The most common standard score is z-score with a mean of 0 and a standard deviation of 1. A raw score can be transformed to a z-score using the formula: $z_i = (x_i - M)/s$, where x_i is the raw score for student i, M is the mean of all student score, and s is the standard deviation for all scores. Positive z-scores are above average, and negative z-scores are below average. Standardized (z) scores were computed using SPSS. Effect size can be interpreted as a kind of z-score. Therefore, effect size uses the concept of 'standard deviation' to explain the difference between two groups.

The results indicate that collectively, prior

Table 3. Correlations between student factors

	10th Grade Math	**10th Grade Science**	**8th Grade Math**	**8th Grade Science**	**Free/Reduced Lunch**	**Female**
10th Grade Science	0.77**					
8th Grade Math	0.77**	0.65**				
8th Grade Science	0.48**	0.55**	0.74**			
Free/Reduced Lunch	–0.39**	–0.42**	–0.38**	–0.34**		
Female	–0.09	–0.05	–0.13	–0.17*	0.12	
PLTW Enrollment	0.14*	0.08	0.10	0.15*	–0.08	–0.38**

NB. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

achievement, free/reduced lunch eligibility, and *PLTW* enrollment account for 60.8% of the variation in math achievement, a significant relationship between prior achievement, free/reduced lunch eligibility, gender, *PLTW* enrollment and student math achievement, $R^2 = 0.61$, $F(4, 171) = 66.21$, $p < 0.001$. Prior achievement alone accounted for 59.0% of the variation in math achievement. Adding free/reduced lunch status to the regression model helped explain 60.1% of the achievement variation. The addition of gender to the model explained only a small amount of additional variation of achievement (60.2%). Adding *PLTW* enrollment variable increased the percentage of variance explained to 60.8%. To assess the statistical significance of the unique contribution of *PLTW* enrollment, we examine its coefficient. Controlling for prior achievement, eligibility for free lunch, and gender, we found that students enrolled in *PLTW* courses scored marginally (0.10 alpha level) significantly higher than *non-PLTW* students (effect size = 0.18). An effect size of 0.18 falls in the range of a 'small effect.' Specifically, it means that the score of the average student in the *PLTW* group exceeds the scores of 57% of the students in the *non-PLTW* group.

For science, prior achievement, student characteristics, and *PLTW* enrollment explained 61% of the science achievement variation, $R^2 = 0.370$, $F(4, 171) = 25.14$, $p < 0.001$. Prior achievement explained 30.7% of the variance in student achievement. Adding free/reduced lunch status to the regression model increased this number to 36.7%. Similar to math, the addition of gender did not explain much additional variance found in student achievement (37.0%). Including *PLTW* enrollment did not improve the model (37.0%). The results show no significant relationship between *PLTW* enrollment and student achievement in science, after controlling for prior achievement and student characteristics, $p = 0.85$. That is, students enrolled in *PLTW* courses did not score significantly higher on science assessment than their non-*PLTW* counterparts.

While the study's focus is on the effects of *PLTW* enrollment and student achievement in science and mathematics, we want to highlight the significant contributions of other factors in explaining student achievement. Our results show that controlling for free/reduced lunch status, gender and *PLTW* enrollment, student prior achievements (8th grade) are significant predictors for current student achievement (10th grade), with the effect size of 0.723 ($p < 0.001$) for mathematics (the upper end of a 'medium' effect size) and 0.474 ($p < 0.001$) for science (the upper end of a 'small' effect size). This suggests that students who did well in 8th grade assessments tended to do well in the 10th grade science and mathematics assessments. Another significant predictor is student eligibility for free/reduced lunch programs (an indicator of socioeconomic status). The results indicate that after controlling for prior achievement, gender, and *PLTW* enrollment, students qualified for free/reduced lunch programs (those from lower socioeconomic background) scored 0.269 standard deviation lower on standardized math assessment ($p = 0.027$) and 0.614 standard deviation lower in science ($p < 0.001$) compared to students who are not eligible for free/reduced lunch programs (those from higher socioeconomic background). It is also important to note that after controlling for other factors, gender does not appear to have an effect on student achievement in science ($p = 0.358$) or mathematics ($p = 0.305$). Table 4 provides a summary of the results.

The multiple regression equations for predicting student achievement in science and mathematics using standardized scores are specified below.

Math achievement =
–0.039 + 0.723*Prior Math Achievement
–0.269*Free/Reduced Lunch + 0.108*Female
+ 0.178*PLTW + ϵ
Science achievement = 0.088 + 0.474*Prior Science Achievement
–0.614*Free/Reduced Lunch + 0.123*Female +
0.026*PLTW + ϵ

The findings for mathematics performance support the *enriched integration hypothesis* in math achievement. The relationship between *PLTW* enrollment and math achievement is marginally significant at the alpha level 0.10, suggesting that the relationship is notable and might be stronger with a larger sample. However, enrollment in *PLTW* courses showed no measurable benefit for 10th grade science achievement. This supports the *insufficient integration hypothesis* and suggests two possibilities: a) little integration between engineering and scientific concepts is taking place to connect to or advance the scientific knowledge and reasoning abilities of students; or b) if the connection

Table 4. Regression analyses predicting student achievement in science and mathematics

	Mathematics			**Science**		
Predictor	**Coefficient**	**SE**	**P**	**Coefficient**	**SE**	**P**
Intercept	–0.039	0.087	0.659	0.088	0.110	0.423
Prior achievement	0.723*	0.052	0.000	0.474*	0.065	0.000
Free/Reduced lunch	–0.269*	0.120	0.027	–0.614*	0.150	0.000
Female	0.108	0.105	0.305	0.123	0.133	0.358
PLTW enrollment	0.178**	0.111	0.110	0.026	0.141	0.854

NB. * Indicates significance at or below the 5% level. ** Indicates marginal significance at the 10% level.

between pre-college engineering content and scientific concepts is made, little impact is shown in student achievement on standardized tests. Below we discuss the implications of these findings.

5. DISCUSSION AND CONCLUSIONS

Overall, *PLTW* enrollment has a marginal, but positive impact for 10th grade math achievement scores, but no measurable effect on science performance. These analyses use correlational techniques, and thus cannot tell us about the causal relationship between *PLTW* enrollment and student achievement in science and mathematics. Similar findings in science achievement have been reported in our previous work with a different district serving a more ethnically diverse student population and a larger number of students who qualified for free/reduced lunch [20]. There have also been alternative studies examining the presence and level of integration of mathematics in *PLTW* and other pre-college engineering curricula [15, 17, 19], suggesting that the pattern is not specific to any one pre-engineering curriculum. While important engineering education objectives in areas of design, analysis and testing are being met, it appears the clarion call for TE to advance academic goals in science and mathematics as well as contributing to one's TE is not being responded to adequately. This is particularly notable because of the high academic standards in math and science for admission to and success in engineering programs at the university level [24]. We conclude the article with specific recommendations for curriculum design and professional development aimed at improving the integration of core science and math concepts within pre-college engineering lessons, and development of alternative assessments that adequately measure student outcomes for pre-college engineering studies. Lastly, we examine some of the policy implications of these findings as educational leaders consider reforming secondary education.

5.1 PLTW and achievement in science and mathematics

In our study, students as a group showed measurable gains in science and math from 8th to 10th grade. It is important to consider student achievement gains in light of other factors that may enhance test performance, such as general developmental maturation and learning from the general middle school and high school curriculum. The role of the comparison group allows us to ask whether the gains observed by students enrolled in *PLTW* courses are significant, above and beyond those exhibited by a similar group of students. In this data set, *PLTW* enrollment is associated with no achievement gains in science tests, above and beyond those gains obtained by students in the comparison group, while math achievement shows modest gains beyond those students who do not take engineering courses. The findings on the relationship between *PLTW* science achievement are consistent with those found in our previous investigation using a different sample [20]. However, the relationship between *PLTW* and math achievement is inconsistent in these two studies—with a positive association between *PLTW* enrollment and math achievement found in this study and a negative association between these two variables exhibited in our previous study [20]. We suspect that differences in these findings may be attributed to the demographics of the students in the samples, a topic we discuss in the following section. Meanwhile, curriculum analyses may show a low level of integration of math and science in pre-college engineering activities, the results reported here and elsewhere [15, 17, 20] are, on the balance, consistent with the *insufficient integration* hypothesis, which suggests that the absence of additional gains in achievement scores may be attributed to little or no integration of the science content knowledge and engineering concepts made for students. We offer three other alternative explanations for the lack of association between *PLTW* and science achievement.

First, we discuss the use of standardized assessment in measuring student learning outcomes. Under the federal requirement of No Child Left Behind Act in 2001 (NCLB), the use of standardized tests has increased drastically to reinforce accountability standards for teachers and administrators. Linn and Gronlund [25] have helped to articulate two sides of the accountability debate. Proponents of high-stakes testing believe that the tests measure objectives that are important for students to learn and the tests can guide teachers to focus their attention on those objectives. Opponents of standardized assessments have pointed out that the tests can be biased against certain groups of students and tend to focus more on (easier to score) factual knowledge and low-level skills at the expense of assessing deep, conceptual reasoning. Therefore, in the current climate, it is not uncommon for important content knowledge to be excluded from a curriculum if it is not included in the assessment—so-called 'teaching to the test.' This underscores the importance of understanding the alignment between standardized tests that purport to measure achievement, and the specific activities and learning objectives of the courses that students enroll in. Poor alignment between what is taught in these engineering courses and what is assessed in general tests of high school science and math must be considered as a factor when interpreting the relationship between course enrollment and achievement scores.

A second alternative explanation explores the degree to which student learning can be transferred across contexts. When there is a close match between the learning activities and the assessment, it is easy to measure the transfer of learning across these two contexts. This 'near transfer' is made possible because of the similarities between tasks that students are asked to perform in these settings [26, 27]. In contrast, 'far transfer' takes place when students acquire deeper understanding of the concepts and thus are able to apply this knowledge in a different context than the one in which learning took place. Thus, the results of this study suggest that we are more likely to be able to detect an effect that is 'near transfer' (when there is good alignment between the learning activity and assessment) than 'far transfer' (when there is poor alignment between the learning activity and assessment).

Third, we suspect student demographics and district characteristics may be attributed to the observed outcomes. Compared to previous research focusing on a more diverse population in an urban setting [20], this study focused on a sample of students coming from a more affluent community. The different results found in these two studies suggest that *PLTW* may have differential effect on student achievement depending on the student demographics and their local context—that is, the *enrichment integration* hypotheses may be more likely to be realized for students from higher social economic backgrounds. In other words, it is plausible to suspect that because of different values, expectations, community demands, parental influences, or even teaching practices, *PLTW* yields greater benefits for students from more affluent backgrounds. This finding is supported by previous research sampling *PLTW* students with similar racial/ethnicity composition showing positive learning outcomes for students enrolled in *PLTW* courses [14]. Further investigation is needed to assess the potential differential impact of *PLTW*.

Since the results of this study were not consistent with those found in the previous investigation [20], in the following section we use descriptive information to explore how the results may vary across contexts (one school district located in a metropolitan area while the other is in an urban setting). Descriptive information on Table 5 shows that students in these two districts vary in student science and mathematics achievement and free/reduced lunch eligibility (an indicator of socioeconomic status). While this information only provides us with descriptive characteristics of the districts and no statistical association can be drawn, in the following section we highlight the significance of student characteristics in predicting their achievement in science and mathematics.

The current results show student prior achievement and socioeconomic status are significant factors explaining a large proportion of the variation of the student achievement in science and mathematics. These findings are consistent with previous research [20] and large-scale policy research in the field of education, supporting the idea that, coupled with prior achievement, the accumulation of characteristics that define social class differences influence student achievement [28]. It is not difficult to imagine how students' current learning experiences in the classroom—their mastery of the content knowledge, engagement level, and attitudes about the subject—can affect how they perform in the future. In addition to the educational experiences that the schools can provide, student social background including their economic status, learning opportunities in out-of-school settings, and parental engagement, just to name a few can have an impact on their learning outcomes. The significant contributions of these two factors—student prior achievement and social background– alone in students' achievement make it a challenging task for the educators to develop instructional practices and curricular approaches that can have long lasting impacts on students' future scholastic and economic opportunities. Thus developers of pre-college engineering programs like *PLTW* must closely examine how the content and learning activities presented in these curricula are connected to student prior knowledge and experiences outside of the classroom. Only then will pre-college engineering experiences in the classroom significantly contribute to the academic preparation needed to pursue advanced studies and careers in engineering for all students.

5.2 Limitations and future work

Even though *PLTW* is a widely distributed curriculum, there is a disproportionately small number of students enrolled in the school or district at any given time. In addition, analyses using gains in student achievement scores require that students have complete data for multiple years. These two factors alone make it challenging for the researcher to obtain a large sample size to conduct meaningful statistical analysis. This study used correlational techniques to examine the relationship between *PLTW* enrollment and student achievement in science and mathematics. Since students were not randomly assigned to *PLTW*

Table 5. Descriptive information of two districts in previous and current studies

	Metropolitan District	**Urban District**
8th Grade Math Achievement	563.69	509.23
8th Grade Science Achievement	417.29	369.92
10th Grade Math Achievement	582.37	523.31
10th Grade Science Achievement	463.20	416.66
Free/reduced Lunch Eligibility	24%	77%

courses, causal inferences cannot be made based on the outcomes produced from these analyses. It is recommended that future studies use larger sample sizes to examine the differential effects of *PLTW* enrollment among students in various sub groups. Also, when feasible, an experimental study should be conducted to determine the causal relationship between *PLTW* and student achievement by assigning students to be in *PLTW* treatment and non-*PLTW* control groups. However, course enrollment is not something casually chosen since it can have profound effects on a student's future. In practice, parents, teachers, guidance counselors and students all weigh in on these decisions. For this reason, there are ethical considerations that also come into play for studies that contemplate randomly assigning students to different courses for purposes of supporting causal inference and hypothesis testing. In this sense, correlational studies based on prior enrollment decisions provide only a partial portrait of the forms of learning that are evident in school settings.

5.3 Conclusions

Based on the results of this study, we provide four important recommendations that can advance our knowledge in the area of pre-college engineering studies and future assessments of their effectiveness. First, we recommend that pre-engineering curricula like *PLTW* make explicit and extensive connection between engineering principles and math and science concepts through various learning activities. This integration can be enhanced by providing on-going professional development training throughout the school year that is specifically aimed at improving the integration of core science and math concepts within pre-college engineering lessons for TE, mathematics and science teachers. Previous investigations on curricular analysis indicate insufficient integration of engineering activities with the central concepts and procedures in college preparatory science and math courses [15, 19]. Yet studies explicitly integrating math instruction with TE courses (in agriculture, auto mechanics, business and marketing, health sciences, and information technology) have been shown to significantly improve students' math performance, without any drop in performance in technical skills [29]. Results from this study are consistent with these findings, suggesting that teachers and staff providing professional development should consider making the integration a more explicit instructional goal. For effective integration to take place, school and district leaders ought to consider professional development approaches that model how pre-engineering concepts can be integrated in math and science academic courses and vice versa. Following the professional development training, school leaders will need to provide on-going instructional support for teachers to implement the newly acquired content and pedagogical skills in the classroom and discuss improvements that can be made for effective integration.

Second, the development of alternative assessments that better align and reflect the skills and knowledge that students are learning in these pre-college engineering courses is much needed. Currently, researchers rely heavily on state and national standardized assessments as indicators to assess instructional effectiveness and measure student learning outcomes. While these assessments are widely utilized as common assessments, they are not designed to assess students' performance skills and comprehension of engineering principles in particular. Course specific assessments are likely to be better aligned with curricular content, but are not likely to be taken by the general student population, most of whom are not enrolled in the specific TE courses. Thus, the design of alternative assessments is crucial to accurately determine the effectiveness of pre-college engineering studies on improving student learning relative to the general student population.

Third, these data provide value to district leaders and policy makers who may be considering revising graduation requirements in science to include pre-engineering courses. While this investigation provides no causal claims about *PLTW* and science achievement, it does suggest that these pre-engineering courses, and perhaps others like them, have limited impact on the forms of science knowledge that may be assessed in current state assessments. In this regard, pre-engineering courses may serve as valuable science electives, perhaps as a precursor to fulfilling graduate requirements. This would allow policy makers to proceed cautiously until data on the impact of pre-engineering on students' scientific achievement are more conclusive.

Lastly, these data re-iterate the strong impact that both academic factors (e.g., prior math and science achievement) and social factors (e.g., family socioeconomic status) have on students' later test performance. Teachers and district staff must continue their efforts to provide quality science and mathematics education in the early grades, and to create a school climate where all students see competency in science and technology is within reach.

REFERENCES

1. NRC, *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology.* National Academy of Sciences, National Academy of Engineering, Institute of Medicine, National Academy Press, Washington, DC, 2007.

2. Public Law pp. 105–332, 1998, http://www.cccs.edu/Docs/SBCCOE/PerkinsAct1998.pdf (last accessed March 2009).
3. M. Rose, *The Mind at Work*. Viking, New York, 2004.
4. D. Laurillard, *Rethinking University Teaching: A conversational framework for the effective use of learning technologies* (Second edition). Routeledge, New York, 2002.
5. Project Lead The Way, 2008, http://www.pltw.org/index.cfm (last accessed July 2008).
6. D. Walcerz, 2009, https://www.trueoutcomes.net/pltw/index.jsf, Accessed on April 27, 2009.
7. L. A. Phelps, J. Johnson and K. Alder, The emerging profile of Project Lead the Way in engineering and technology education: Findings from a national survey of state leaders, *Final Report*, Madison, WI: Center on Education and Work, University of Wisconsin-Madison (2006).
8. M. Sanders, The nature of technology education in the U.S., *American Society of Engineering Education (ASEE*), 2008.
9. K. Gray, Is high school career and technical education obsolete? *Phi Delta Kappan*, **86** (2), 2004, pp. 128–134.
10. K. Levesque, D. Lauen, P. Teitelbaum, M. Alt, and S. Librera, *Vocational education in the United States: Toward the Year 2000* (NCES 2000–029). U. S. Department of Education, National Center for Education Statistics, Washington, DC (2000), Retrieved May 21, 2009, from http://nces.ed.gov/pubs2000/2000029.pdf
11. S. Plank, Career and technical education in the balance: An analysis of high school persistence, academic achievement, and post-secondary destinations. Columbus: Ohio State University, National Center for Dissemination, 2001.
12. J. J. Kemple and J. C. Snipes, Executive summary: Career academies impacts on students' engagement and performance in high school, Manpower Development Research Corporation, New York, 2000.
13. J. J. Kemple, Career Academies: Impacts on Labor Market Outcomes and Educational Attainment, Manpower Demonstration Research Corporation, New York, 2004.
14. G. Bottom and J. Uhn, Project Lead The Way Works: A new type of career and technical program. *Southern Regional Education Board,* September, 2007, Retrieved May 20, 2009, from http://www.sreb.org/programs/hstw/publications/2007pubs/07V29_Research_Brief_PLTW.pdf.
15. M. J. Nathan, N. Tran, L. A. Phelps and A. Prevost, The structure of high school academic and pre-engineering curricula: Mathematics, In *Proceedings of the American Society of Engineering Education Annual Conference and Exposition,* Pittsburgh, PA, 2008.
16. National Council of Teachers of Mathematics, *Principles and standards for school mathematics*. Reston, VA, 2000.
17. K. Welty, L. Katehi, G. Pearson and M. Feder, Analysis of K-12 Engineering Education Curricula in the United States—A Preliminary Report, In *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Pittsburgh, PA, 2008.
18. S. D. Sheppard, K. Macatangay, A. Colby and W. Sullivan, *Educating Engineers: Designing for the Future of the Field*. The Carnegie Foundation for the Advancement of Teaching (2009), http://www.carnegiefoundation.org/dynamic/publications/elibrary_pdf_769.pdf (last accessed March 2009).
19. A. Prevost, M. J. Nathan, B. Stein, N. Tran and L. A. Phelps, Integration of mathematics in pre-engineering: the search for explicit connections, In *Proceedings of the American Society of Engineering Education (ASEE)*, Austin, TX, 2009.
20. N. A. Tran and M. J. Nathan, An investigation of the relationship between pre-college engineering studies and student achievement in science and mathematics, *Journal of Engineering Education*, **99**(2): 143–158.
21. J. Carroll, A model of school learning, *Teachers College Record,* **64**, 1963, pp. 723–733.
22. E. Forman and C. B. Cazden, Exploring Vygotskian perspectives in education: The cognitive values of peer interaction. In J. Wertsch (ed.), *Culture, communication and cognition*, pp. 323–347. Cambridge University Press, Cambridge, England, 1985.
23. J. Bransford, A. Brown and R. Cocking, *How People Learn: Brain, Mind, Experience and School.* National Academy Press, Washington, DC, 2000.
24. R. M. Felder and R. Brent, Designing and teaching courses to satisfy the ABET engineering criteria, *Journal of Engineering Education,* **92** (1), 2003, pp. 7–25.
25. R. Linn and N. Gronlund, *Measurement and Assessment in Teaching* (8th ed.). Prentice-Hall/Merrill, Upper Saddle River, NJ, 2000.
26. S. M. Barnett and S. J. Ceci, When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin,* **128**, 2002, pp. 612–637.
27. D. N. Perkins and G. Salomon, Transfer of Learning, *International Encyclopedia of Education*, (Second Edition). Pergamon Press, Oxford, England, 1992.
28. R. Rothstein, *Class and schools: Using social, economic, and educational reform to close the black-white achievement gap*. Economic Policy Institute, Washington, DC, 2004.
29. J. R. Stone, III, C. Alfeld and D. Pearson. Rigor and relevance: Enhancing high school students' math skills through career and technical education. *American Educational Research Journal,* **45**, 2008, pp. 767–795.

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