# Pre-College Engineering Studies: An Investigation of the Relationship Between Pre-college Engineering Studies and Student Achievement in Science and Mathematics

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**BACKGROUND**
The U.S. has experienced a shift from a manufacturing-based economy to one that overwhelmingly provides services and information. This shift demands that technological skills be more fully integrated with one's academic knowledge of science and mathematics so that the next generation of engineers can reason adaptively, think critically, and be prepared to learn how to learn.

**PURPOSE (HYPOTHESIS)**
*Project Lead the Way* (PLTW) provides a pre-college curriculum that focuses on the integration of engineering with science and mathematics. We documented the impact that enrollment in *PLTW* had on student science and math achievement. We consider the *enriched integration* hypothesis, which states that students taking *PLTW* courses will show achievement benefits, after controlling for prior achievement and other student and teacher characteristics. We contrast this with alternative hypotheses that propose little or no impact of the engineering coursework on students' math and science achievement (the *insufficient integration* hypothesis), or that *PLTW* enrollment might be negatively associated with student achievement (the *adverse integration* hypothesis).

**DESIGN/METHOD**
Using multilevel statistical modeling with students ($N$ = 140) nested within teachers, we report findings from a quantitative analysis of the relationship between *PLTW* enrollment and student achievement on state standardized tests of math and science.

**RESULTS**
While students gained in math and science achievement overall from eighth to tenth grade, students enrolled in *PLTW* foundation courses showed significantly smaller math assessment gains than those in a matched group that did not enroll, and no measurable advantages on science assessments, when controlling for prior achievement and teacher experience. The findings do not support the enriched integration hypothesis.

**CONCLUSIONS**
Engineering education programs like *PLTW* face both challenges and opportunities to effectively integrate academic content as they strive to prepare students for college engineering programs and careers.

**KEYWORDS**
K-12 engineering education, math achievement, science achievement

## I. INTRODUCTION

Since its emergence in the late nineteenth century industrial arts has faced the challenge of realizing the goal of providing "technological literacy for all" (Sanders, 2008). At the K-12 level, this challenge is between the opposing forces of technical education—aimed at specific, job-related skill training—and general education—which emphasizes broad intellectual development and the knowledge, skills, and critical thinking that we expect from a liberal arts program (Sanders, 2008). Technical Education (TE), as it is conceptualized today, is intended to offer students a general education in the Deweyan sense, providing a general academic education that is grounded in work and that "maintains a balance between the intellectual and practical phases of experience" (Dewey, 1899, 1915, p. 131). In this study, we examine student achievement in the context of a TE pre-college engineering curriculum.

The U.S. has experienced a shift from a manufacturing-based economy to one that overwhelmingly provides services and information. This shift demands that technological skills be more fully integrated with one's academic knowledge of science and mathematics so that the next generation of engineers can reason adaptively, think critically, and be prepared to learn how to learn (Committee on Science, Engineering, and Public Policy, 2007). Technology education is rich with many of the physical, practical, situated, collaborative, and socially relevant attributes of learning that are called for in current educational reform (Bransford, Brown, and Cocking, 2000; Confrey and Stohl, 2004). Yet TE, like industrial arts education before it, reveals a fundamental paradox (Rose, 2004): American institutions of public education are responsible for both the intellectual development and economic preparedness of our youth. However, in practice, TE programs often lack the theoretical content and formal reasoning needed to support later generalization, abstraction, and lifelong learning. Inversely, post-primary general education often lacks the opportunities for developing students' experience-based knowledge, emphasizing instead abstract descriptions and symbolic representations of the actual world (Laurillard, 2002). Rather than bridging this dichotomy, the tendency within formal education is to reinforce age-old stereotypes about who should have access to college preparation and who is directed toward a career-oriented training (Rose, 2004).

### A. Integration of Academic and Technical Education

The Federal legislation that defines and provides funding for TE strives to address this shortcoming. Historically, TE and academic tracks were explicitly separated. Through the Carl D. Perkins Vocational Education Act of 1990, as amended in 1998, the Federal government mandated that capital be made available to institutions "on improving educational programs leading to academic and occupational skill competencies necessary for work in a technologically advanced society" (Pubic Law 105-332). TE programs at the high school level should, then, provide students with both college and career preparation.

One immediate outcome is that high schools that provide TE exclusively are becoming more rare, as students who pursue both academic and TE typically attend the same schools. Consequently, studies of the prevalence and impact of TE require examinations of students' school transcripts, so that course enrollment patterns are properly identified. Analyses of students' transcripts show that, despite its elective status, nearly all students currently participate in some form of TE, including business, family and consumer education, marketing, agriculture, and pre-college engineering. Furthermore, 25 percent of TE enrollees are considered "concentrators," taking three or more courses in a common career track alongside their regular high school program (Gray, 2004).

While the competing tensions between technical and general education have not been resolved, few studies have examined the integration of TE and academic learning, particularly the impact of TE courses on subject area-specific student achievement. There are some notable findings about TE in the literature, however. Typically, there are no significant differences by race or gender between TE participants and the current general student population (Gray, 2004). The majority of TE concentrators go on to college, not directly to work; 80 percent complete the same number of math and science high school course credits as their academic-only peers; and although TE concentrators as a group enter high school less prepared than academic-only students, that gap is narrowed and may even be eliminated by the time they reach graduation (Levesque et al., 2000; Plank, 2001).

As a related area of research, a number of studies have examined career academies—college-preparatory curricula with career themes and established partnerships with community businesses. These studies showed 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 (Kemple, 2004; Kemple and Snipes, 2000).

### B. Pre-college Engineering Education: The *Project Lead the Way* Curriculum

Because technology is playing a bigger role in our personal lives—in manufacturing, healthcare, government, personal and national security, entertainment, and most every other facet of contemporary society—the work of engineers touches our lives more directly. Engineering is central to economic development because of its tight connection to technological innovation, financial investment, and business. Engineering education has also gained tremendous attention in the U.S. because of fears that the pool of qualified engineers in the U.S. may be shrinking relative to the growing demand (Steering Committee of the National Engineering Education Research Colloquies, 2006; Vest, 2008). With "design" as a pedagogical tool used to generate student interest in engineering studies, the partnership between TE—with its emphasis on technological design—and engineering education is a natural one. The growing trend for the integration of engineering concepts in TE over the last two decades signifies the collaboration between post-secondary engineering programs and general education programs in grades 6–12 (Sanders, 2008). As previously described, the close connection of engineering education to science and math education provided for us a focus within the field of TE on pre-college engineering education.

*Project Lead the Way (PLTW)* provides curricula for the middle and high school levels, with seven high school courses accredited for college credit. At the middle school level, the *Gateway to Technology* program organizes 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*. In addition, high school specialization courses include: *Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, and Computer-Integrated Manufacturing*, with an engineering research capstone course entitled, *Engineering Design & Development*. The *Pathway to Engineering*™ curriculum is designed to target students in secondary education who are aspiring to pursue postsecondary engineering studies.

*PLTW* is one of the most widely used pre-college engineering programs in middle and high schools throughout the U.S. Approximately 85 percent of all teachers who teach *PLTW* courses are TE teachers who were likely to receive their TE training during their baccalaureate years and have had TE teaching experiences (Sanders, 2008). *PLTW* offers a multi-year, problem-based/project-based curriculum that has been adopted by over 1,400 schools (over 7 percent of all U.S. high schools) in all 50 states and the District of Columbia (PLTW, 2008a). In 2005, *PLTW* showed a significant pattern of growth in 75 percent of the reporting states that had already implemented the program, indicating an increased awareness and demand for the program and pre-college engineering courses (Phelps et al., 2005). Though it is not a pre-requisite for *PLTW* enrollment, 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 prior to entering college (PLTW, 2008a). However, 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, that result from enrolling in some or all of the courses provided in the curriculum. In addition, the NRC report (2007), *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.

To date, we have found one 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 (2007) found that *PLTW* students who have completed at least three *PLTW* courses scored higher in math and science NAEP assessments 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.

Everyone teaching *PLTW* courses must attend an extensive professional development program, including training provided by *PLTW*'s network of affiliate colleges and universities. The professional development training aims to make teachers proficient in project- and problem-based instruction (PLTW, 2008a). In addition to hosting summer training institutes and ongoing professional development, national affiliates offer graduate college credits opportunities for teachers. We have not found evidence to support the effectiveness of *PLTW* professional development.

*PLTW* is an appropriate choice of curriculum for our studies of the impact of pre-college engineering on science and math achievement because of its widespread use and the program's stated focus on integration for science and mathematics. Specifically, as reported in the *PLTW* curriculum (2004), "Project work and systematic instruction can be seen as providing complementary learning opportunities. Students will know how to use a skill but also when to use it. They will learn to recognize, for themselves, the contexts in which a skill might be useful and what purposes it most appropriately will serve." Still, it is important to note that *PLTW* is only one exemplar for understanding the relationship of student academic achievement in math and science to pre-college engineering education. Each program is unique and fosters its own approach to teaching and learning. Therefore, any findings associated with *PLTW* cannot be generalized to other pre-college engineering studies.

### C. Using Standardized Assessments to Measure Student Learning Outcomes

The Federal requirement of No Child Left Behind in 2001 (NCLB) has greatly increased the use of standardized tests by requiring accountability standards for teachers and administrators. Under this Federal mandate, the state must create content standards in math and reading and assessments that correspond to those standards for grades 3 through 8. Science content standards and assessments followed subsequently (Linn, Baker, and Betebenner, 2002). In addition, each state must develop objectives to meet their adequate yearly progress (AYP) for all students, including students from major racial/ethnic groups, students who have been identified for special education, those from low-income families, and English Language Learners, to reach or exceed the *proficient* level by the 2013–2014 academic year. Schools that fail to meet their AYP objectives will be classified as schools in need of improvement (U.S. Department of Education, 2004). In this era of education reform, assessments are tools used to provide evidence for educators, policy makers, and parents to determine school effectiveness. Some may go as far to argue that, "pupils' performances on tests serve as the single most significant indicator of a school system's success" (Popham, 1990, p. xii).

Proponents of high-stakes testing argue 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. However, opponents of standardized assessments have pointed out that the tests can be biased against certain groups of students and tend to focus more on factual knowledge and low-level skills at the expense of deeper conceptual reasoning. Therefore, it is not uncommon for content knowledge to be excluded from the curriculum if it is not included in the assessment (Linn and Gronlund, 2000).

While the controversy on standardized assessment remains, testing continues to play an integral part of instruction (Linn, 1989). Many school districts administer assessments at selected grade levels. In general, assessment is used for multiple purposes: monitoring student achievement, providing school accountability, reporting to parents, or making decisions about students' course enrollment or graduation from high school. As a result, most students have considerable experience with a variety of standardized tests before leaving high school (Linn and Gronlund, 2000). We acknowledge that while the state assessments may not be adequate to measure all aspects of student learning, they have the unique properties that (a) all students are taking them regardless of their curricular program or post-secondary plans, and (b) students take them at common points in their scholastic programs, providing consistent measures to document baseline performance and changes in achievement.

Like many other school districts, the district that participated in our study administers assessments to students in the grades 3–8 and grade 10. Student performance on these assessments is reported in proficiency categories and used to determine the AYP of students at the school, district, and state levels. According to the state department of education, the objectives for mathematics assessments are to measure students' skills and knowledge in the following areas: (a) mathematical process (reasoning, communication, connections, representation, and problem solving); (b) number operations and relationships (number concepts, number computation); (c) geometry (describing figures, spatial relationships and transformations, and coordinate systems); (d) measurement (measurable attributes, direct measurement, indirect measurement); (e) statistics and probability (data analysis and statistics, probability); (f) algebraic relationships (patterns, relations and functions, expressions, equations and inequalities, properties). In science, the objectives include: (a) science connections; (b) nature of science; (c) science inquiry; (d) physical science; (e) earth and space science; (f) life and environmental science; (g) science applications; and (h) science in social and personal perspectives. The state uses criterion-referenced tests to measure students' cognitive ability to perform on specific criteria. The five proficiency categories representing these criteria are: prerequisite skill, minimal performance, basic, proficient, and advanced. Items on the tests include selected-response (multiple-choice) and constructed-response (short answer). Approximately 80 percent of a student's score points will come from selected-response items, and 20 percent from constructed-response items.

## II. Hypotheses of the Study

If we assume that high school *PLTW* students are receiving instruction and practice time on science and math above and beyond that of the regular academic program, it follows that pre-college engineering enrollment may be associated with higher levels of subject area-specific achievement. Furthermore, the *PLTW* developers commissioned a recent study on the level of math and science content addressed in the *Introduction to Engineering Design* course, which contends that strategic thinking is used throughout the curriculum "to prepare an increasing and more diverse group of students to be successful in science, mathematics, engineering, and engineering technology" (PLTW 2008b, p. 2). Specifically, the report concluded that "a large proportion of the objectives in this course were identified for emphasizing content from the mathematics and/or science standards" (PLTW, 2008b, p. 38). Based on this, it follows that students enrolled in *PLTW* courses may be expected to show additional benefits from the exposure of math and science content knowledge in an engineering context above and beyond the curriculum material presented in the academic courses taken by them and their non-*PLTW* peers. This leads us to consider the *enriched integration* hypothesis, which states that students taking one or more courses from the high school *PLTW* curriculum at certified schools will exhibit higher standardized test scores in science and mathematics than the students who are not taking any *PLTW* courses, after controlling for prior achievement and other student and teacher characteristics. To address this hypothesis, we present multi-level statistical analyses to estimate the relationship between *PLTW* enrollment and student achievement. While causal claims are not supported by this type of analysis, we do note that one of the best predictors of achievement is time on task (Carroll, 1963; Forman, and Cazden, 1985). That is, if the integration of science and math topics is effectively implemented, then at a minimum, those taking *PLTW* courses should experience increased time spent learning mathematics and science. Furthermore, since the *PLTW* curriculum is designed to engage students in hands-on and real-world projects, students can make connections between the knowledge and skills they are learning 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 (Bransford et al., 2000). Thus, there may be additional benefits for learning if, in addition, these pre-college engineering curricula foster conceptual understanding through first-hand experiences that would ordinarily fall outside of the academic learning experiences of the regular math and science classes.

There is, of course, a set of alternative hypotheses. 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. In this case, we might expect that *PLTW* enrollment will have no association with student achievement in mathematics and science, and gains for pre-college engineering studies will be no different than for other students who are not enrolled in these courses.

Finally, we acknowledge *PLTW* enrollment might be negatively associated with student achievement. The *adverse integration* hypothesis predicts that science and mathematics achievement scores for *PLTW* students are lower than their peers not enrolled in *PLTW* courses, after controlling for prior achievement and other student and teacher characteristics. The pre-college engineering educational experience has many unique qualities to it that differ greatly from the typical math or science classroom. 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 and are exhibited by lower gains than students who are not enrolled in *PLTW* courses.

## III. Method

Research in education and other social sciences tend to have data with hierarchical structure (students nested in classrooms and classrooms nested in schools nested in districts). The nesting of individuals into groups may affect the outcomes of the study (i.e., student achievement in a classroom with a novice teacher vs. student achievement in a classroom with a veteran teacher). One can see that students' performance can be affected by the characteristics of the teachers. As the result, variation in student achievement can be found between teachers. Due to the nested structure of the data with student at level 1 and teacher at level 2, we cannot ignore the variability associated with each level of the hierarchy. Given the multi-level structure of the data used in this analysis, with students nested in classrooms, we applied multi-level statistical modeling (Raudenbush, 1997; Snijders and Bosker, 1999) to estimate the effects of classrooms on mathematics and science achievement. Various two-level models were estimated. At Level 1, we used students' demographics and prior achievement test scores at the middle school level (eighth grade) to predict students' achievement in mathematics and science during high school (tenth grade). At level 2, teacher experience was used as a predictor for student achievement. We estimated the relationship between student enrollment in one or more of the *PLTW* foundation courses (PLTW) and student achievement after controlling for both student and teacher characteristics. Activities involving data collection and analysis were done with approval of the IRB of the University of Wisconsin, as well as the participating school district.

### A. Sample Selection

Our sample of students is drawn from a Midwestern city with a mid-sized (over half million), urban population. In the 2007–2008 academic year, the district enrolled over 87,000 students (K-12) with 49 percent female and 51 percent male. Fifty seven percent of the students in the district were listed as African American, 22 percent Hispanics, 12 percent White, 4 percent Asian, and 4 percent Other. Approximately 72 percent of the students in the district came from low-income families who were eligible for free/reduced lunch through the National School Lunch Program. Students identified for special education services made up 18 percent of the student body, greater than the national average (12 percent), while English Language Learners made up 8 percent of the school population.

Within this school district, the specific data sample of interest consists of students enrolled in five high schools that are implementing the *PLTW* curriculum *Pathway to Engineering*™. While the math and science courses at these high schools may vary in content, all teachers in the district are directed to adhere to the grade-specific math and science content standards for the state, which serve as a guideline for their instructional practices. In addition, each year all eighth and tenth grade students in the district are required to take the same math and science state standardized assessments. We restricted our analyses to students attending schools offering *PLTW* courses to provide the best comparison groups for our analyses. In order to be a "*PLTW* school," and offer *PLTW* courses, a school must purchase instructional equipment (with fixed start-up costs of $120,000) for each classroom (up to 24 students per classroom) and participate in a two-week *PLTW* training for the instructor of each course, along with a two-day training for least one guidance counselor from each school.

To examine the relationship between *PLTW* enrollment and student achievement, we used the school district database to develop a sample of students from the five *PLTW*-accredited high schools who completed the state assessments at two points in time. We identified all *PLTW* students with complete data and then identified their non-*PLTW* counterparts. Since the assessments are given only at fourth, eighth and tenth grade, and formal electronic data collection procedures have only been in place in the school district since 2005, this restricted the sample to only those students who have eighth grade (2005–06) and tenth grade (2007–08) achievement data. The total number of tenth grade students enrolled in these five schools is 1,271 with 139 (11 percent) students enrolled in at least one *PLTW* course (*PLTW* student).

Our analysis required that students have complete data. Using SPSS, respondents were divided into two groups, those with and without missing data. Cross-tabulation was used 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 two categorical variables are not related with alpha level set at 0.05. Overall, the results showed that—with the exception of gender ($p = 0.003$)—differences in free/reduced lunch eligibility ($p = 0.748$), African American ($p = 0.828$), Asian ($p = 0.613$), Hispanic ($p = 0.135$), White ($p = 0.081$), Other ($p = 0.853$), and special education status ($p = 0.890$) were not statistically different between students with missing data and those without missing data. The analysis above suggests that the data maybe *missing at random*, and therefore the subsample of students with no missing data is expected to provide an unbiased sample (Allison, 2002).

Listwise deletion was used to remove 449 students with missing data, resulting in 772 students (67 percent) with complete data. The final sample size consists of 140 students with 27 teachers. The range of the number of students for each teacher is 1 to 31 with an average of five students per teacher. From this group, only 70 students enrolled in one or more *PLTW* courses.

A comparison group of 70 students was then "hand picked" from the larger sample that matched the *PLTW* group on three criteria: prior achievement in science and mathematics, gender, and free/reduced lunch eligibility. This hand-matching technique was used to create the best comparison group for the *PLTW* group. In addition, the selection technique resulted in two groups of students with comparable course enrollment in science and mathematics. There is naturally some variation in course names and content across the schools. However, with the assistance of the school district personnel, we were able to classify these courses into broader categories: remedial math (basic math), core math (Algebra, Geometry, Trigonometry), advanced math (Pre-calculus, Calculus, AP Calculus), general science (Integrated Science, Earth science, Physical Science, Life Science), core science (Biology, Chemistry, Physics), and advanced science (AP Biology, AP Chemistry, AP Physics). Overall, a large proportion of the students in our sample enrolled in core math and core -science courses. Table 1 provides a summary of student course enrollment for *PLTW* and non-*PLTW* groups.

| | PLTW | Non-PLTW |
|---|---|---|
| Remedial math | 0 (0%) | 0 (0%) |
| Core math | 68 (97%) | 70 (100%) |
| Advanced math | 0 (0%) | 0 (0%) |
| Missing | 2 (3%) | 0 (0%) |
| General science | 0 (0%) | 2 (3%) |
| Core science | 63 (90%) | 64 (91%) |
| Advanced science | 0 (0%) | 0 (0%) |
| Missing | 7 (10%) | 4 (6%) |

*Table 1. Student course enrollment for PLTW and non-PLTW groups.*

Although matching students by the school they attended could potentially reduce the variability between students in the *PLTW* and non-*PLTW* groups, the relatively small sample size did not allow us to include school as a matching variable. Instead, we focused our matching criteria on student prior achievement, gender, and free/reduced lunch status. While the student data for each school are not similar, we are confident that the student characteristics we selected can explain a large proportion of variance in student achievement.

The final demographics of the study sample are shown in Table 2. Approximately 72 percent of these students were eligible for the Federal free/reduced lunch program. The sample was comprised of a diverse student population with 49 percent African American, 24 percent Hispanic, 14 percent White, 9 percent Asian, and 3 percent Other (the percentages of student ethnicity for each school may not equal 100 due to rounding). The fraction of male students (59 percent) is higher than female students (41 percent). Approximately 9 percent of the students were designated for special education services. An equal proportion of students enrolled in *PLTW* courses compared to their non-*PLTW* counterparts (50 percent).

To address the potential problem of the selection bias that may be associated with the sampling procedure employed in this study, we conducted a separate analysis using a different sampling technique known as propensity score matching (PSM). The PSM approach calculates the conditional probability of assignment to treatment given a set of observable covariates. This allows for balancing of the observed covariates, thereby creating a dataset similar to participants being assigned to treatment or control under true randomization. This eliminates much of the bias associated with self-selection (Rosenbaum and Rubin, 1984). We derived the propensity scores from the group of students with complete data ($N = 772$). We then compared the PSM results with the results we obtained from hand matching the data (for the technical details, see Tran, Nathan, and Nathan, 2009). Applying the same regression equation used to estimate *PLTW* impact on student achievement in science and mathematics, the descriptive statistics show that the characteristics for the *PLTW* group, hand-matched comparison group, and PSM comparison group are, respectively, very similar in prior achievement in math (508.73 for the *PLTW* group, 509.73 for hand-matched comparison, and 509.19 for comparison selected with PSM) and science (368.77 for the *PLTW* group, 371.73 hand-matched comparison, and 372.52 for comparison selected with

| School | African American | Asian | Hispanic | White | Other | Female | Special Education | Free/ Reduced Lunch | PLTW Enrollment |
|---|---|---|---|---|---|---|---|---|---|
| Benjamin[a] | | | | | | | | | |
| % | 65.3[*] | 0.00 | 26.5 | 8.2 | 0.0 | 42.9 | 14.3 | 83.7 | 73.5 |
| Raw | 32 | 0 | 13 | 4 | 0 | 21 | 7 | 41 | 36 |
| Hilldale | | | | | | | | | |
| % | 22.2 | 25.9 | 11.1 | 40.7 | 0.0 | 44.4 | 7.4 | 48.1 | 22.2 |
| Raw | 6 | 7 | 3 | 11 | 0 | 12 | 2 | 13 | 6 |
| Richmond | | | | | | | | | |
| % | 68.8 | 0.00 | 12.5 | 18.8 | 0.0 | 37.5 | 12.5 | 68.8 | 0.0 |
| Raw | 11 | 0 | 2 | 3 | 0 | 6 | 2 | 11 | 0 |
| Sinclaire | | | | | | | | | |
| % | 32.2 | 19.4 | 41.9 | 0.0 | 6.5 | 45.2 | 9.7 | 90.3 | 48.4 |
| Raw | 10 | 6 | 13 | 0 | 2 | 14 | 3 | 28 | 15 |
| Western | | | | | | | | | |
| % | 94.1 | 5.9 | 0.0 | 0.0 | 0.0 | 29.4 | 29.4 | 88.2 | 76.5 |
| Raw | 16 | 1 | 0 | 0 | 0 | 5 | 5 | 15 | 13 |

[a] *Nota bene*. School names are pseudonyms.
[*] The numbers are rounded to 3 significant digits.

*Table 2. Characteristics of students in the study sample (N = 140).*

PSM). Similar characteristics are also observed for the proportion of students qualified for the free/reduced lunch program and gender. More importantly, the results indicate no statistical differences in estimates of the treatment on student achievement between the hand-matched and PSM techniques, suggesting that these two sampling techniques do not affect the impact of the treatment on student achievement. While both the hand-selection and PSM approaches do not completely eliminate all significant observable and unobservable biases that may exist in *PLTW* and non-*PLTW* groups, our investigation has shown that matching techniques used to derive the results of this study is comparable to other methodological approaches used in quasi-experimental research.

Descriptive statistics show that of the 70 *PLTW* students included in our sample, 58 students had enrolled in one *PLTW* course (54 in Introduction to Engineering Design, 1 in Principles of Engineering, and 3 in Digital Electronics). The remaining 12 students had enrolled or completed two *PLTW* courses (Introduction to Engineering Design, Principles of Engineering). An independent *t*-test and a one-way ANOVA were applied to test the null hypothesis that the means of *PLTW* and non-*PLTW* groups are equal. The results indicate that differences are found in the between-groups and within-groups Mean Squares for math achievement (14.900 for between-group and 2306.126 for within-group) and science achievement (40.230 for between-group and 1407.908 for within-group) respectively, resulting in a non-significant difference for math ($F = 0.0006$, *Sig.* $= 0.936$) and science ($F = 0.029$, *Sig.* $= 0.866$). Thus, the average achievement score of students in *PLTW* and non-*PLTW* groups are statistically indistinguishable. The results also suggest that even though the sample sizes in the two groups are unequal, this does not imply they have unequal variance. Therefore, the use of *t*-tests is appropriate.

Once the sampling group of students was identified, we linked each student's information to teacher characteristics (years of experience, gender, degree). Since there is a relatively small number of *PLTW* courses offered in a given school or district, teachers who teach *PLTW* courses may also teach other non-*PLTW* courses. Therefore, it is possible that some *PLTW* and non-*PLTW* students will have the same teachers. For example, students who did not take *PLTW* courses may or may not have the same teachers as *PLTW* students. Due to the small number of *PLTW* courses available in the schools, teachers in the sample instruct both *PLTW* and non-*PLTW* courses. Unfortunately, we do not have data on teacher certification, though the data available for the teacher characteristics include gender, highest degree attained, and years of teaching experience. There is a slightly larger number of male teachers, a large proportion of the teachers received their bachelor degrees, and close to half the teachers have ten or more years of teaching experience. Table 3 provides a description of teacher characteristics in the study.

**B. Measures**

***1) Student Achievement:*** The school district provided measures of student achievement, including 2005–06 and 2007–08 results from state standardized tests for current tenth-grade students in mathematics and science. Both math and science assessments were administered to students in November, 2005 (eighth grade) and again in November, 2008 (tenth grade). These standardized tests are designed to measure the state academic standards in mathematics and science using multiple-choice and short-answer questions. The scale scores and proficiency categories (advanced, proficient, basic, and minimal performance) for math (range 350–730 for eighth grade, and 410–750 for tenth grade) and science (range 230–560 for eighth grade, and 240–610 for tenth grade) are explicitly stated.

***2) Student (Level 1) Variables:*** The district provided data on student characteristics including prior achievement in state-wide standardized tests in mathematics and science, gender, 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* foundation courses = 1). These variables, along with student prior achievements (2005–06 in eighth grade) in mathematics and science, were included as predictors at

| | Gender (N = 27) | | Highest Degree (N = 27) | | Years of Experience (N = 27) | | |
|---|---|---|---|---|---|---|---|
| | Female | Male | Masters | Bachelors | 3 years or less | 4–10 years | 11 years or more |
| Number | 14 | 13 | 11 | 16 | 8 | 8 | 11 |
| Percent | 52% | 48% | 41% | 59% | 30% | 30% | 40% |

*Table 3. Description of teacher characteristics in the study (N = 27).*

Level 1 of the multi-level analysis described in the following section.

*3) Teacher (Level 2) Variable:* In addition to student information, we obtained data on teacher years of experience from the district. This variable allowed us to explore the relationship between teacher experience and student achievement. We also have data related to school characteristics. However, we did not have enough schools in our sample ($N = 5$) to estimate a meaningful three-level model. Table 4 provides a summary of the variables used in Level 1 and Level 2.

### C. Analysis

In our analysis, we consider whether there is a teacher effect on student achievement in science and mathematics. If there is a high proportion of variance between teachers, then a multi-level model is needed to adjust the standard errors. Multi-level analysis accounts for the cluster level effect on student performance. That is, students with the same teacher are not independent of each other and one student's score can be used to predict the score of another student who has the same teacher. This dependence can be explained by the intra-cluster correlation (ICC), the proportion of variance of student achievement found at the teacher level. Given that students are nested within teachers, variance across the different teachers can be documented using baseline characteristics. In this case, the assumption is that the intra-cluster correlation (ICC) will not be zero. Analysis of the intra-cluster correlation (ICC) for student achievement in mathematics and science yielded ICC values of 0.29 and 0.26, respectively. This suggests that there is some variation in student achievement at the teacher level. Our descriptive analysis also shows that teachers' years of experience are negatively associated with student achievement in math and science. Thus, each teacher's years of experience is used to predict variation in student achievement at the teacher level. Therefore, the use of a Hierarchical Linear Model (HLM) is the most appropriate method to determine the relationship between two variables (Raudenbush, 1997).

A two-level model is used to determine the relationship between student enrollment in *PLTW* and student achievement in mathematics and science. If there is variation across teachers, then the random-effects approach is used and significant effects can be generalized to the larger population beyond the sample classrooms. This analysis assumes comparison of observations from different normal distributions. Descriptive statistics and graphs of student achievements indicate that the mathematics (mean = 523.31; standard deviation = 44.252) and science (mean = 416.66; standard deviation = 36.301) achievements did not violate this assumption.

In order to test our hypotheses about the relationship between *PLTW* enrollment and student achievement, we first fit the models with no predictors at either level (unconditional models) to provide us with the amount of variation available to be predicted at each level. Then, a random intercept model was estimated with exploratory variables (prior achievement, student demographics, and *PLTW* enrollment) at Level 1 with no Level 2 (i.e., teacher) predictors.

The Level 1 model was specified as:

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

This represents achievement regressed on the prior achievement score, gender, free/reduced lunch status, *PLTW* enrollment, and the Level 1 residual variance ($R$), which is assumed to be normally distributed with a mean of 0 and variance $\sigma^2$. All Level 1 predictors were grand-mean centered. In this way, $\beta_0$ can be interpreted as the expected achievement outcome for a student whose values on the predictor variables are equal to the grand means of those predictors.

Next, the Level 2 prediction models were estimated for the random intercepts but the random effects for each of the slope parameters were fixed. Teacher experience was included as a Level 2 predictor. The Level 2 model was specified as:

$$\beta_0 = \gamma_{00} + \gamma_{01}\text{Years Experience} + U_0$$
$$\beta_1 = \gamma_{10}$$
$$\beta_2 = \gamma_{20}$$
$$\beta_3 = \gamma_{30}$$
$$\beta_4 = \gamma_{40}$$

Here, classroom mean achievement is regressed on teacher years of experience and the classroom residual variance ($U_0$). The Level 2 predictor was not grand-mean centered to maintain parsimonious interpretation. In this case, the zero value in teacher years of experience serves as a reference value. The intercept could be interpreted as the expected score for a student whose teacher has zero years of teaching experience. The slopes for all Level 1 ($\beta_1 - \beta_4$) variables were treated as fixed.

## IV. Results

First, paired sample $t$-tests for the group as a whole ($N = 140$) indicate significant gains of student achievement in mathematics ($p < 0.01$) and science ($p < 0.01$) from eighth grade to tenth grade. Moderately high correlations (0.73 for math and 0.77 for science, respectively) between eighth grade and tenth grade achievement tests suggest that students who did well on eighth grade mathematics tests tended to do well on tenth grade mathematics tests, with the same relationship for the eighth and tenth grade science tests.

Second, Table 5 displays the proportion of current year (2007–08) test score variance at the teacher level and the reliabilities

| Variable | PLTW N | PLTW Mean | PLTW Standard Deviation | PLTW Minimum Score | PLTW Maximum Score | Non-PLTW N | Non-PLTW Mean | Non-PLTW Standard Deviation | Non-PLTW Minimum Score | Non-PLTW Maximum Score |
|---|---|---|---|---|---|---|---|---|---|---|
| **Teacher level** | | | | | | | | | | |
| Years of experience | 10 | 8.83 | 8.54 | 1.00 | 24.00 | 25 | 10.60 | 7.58 | 0 | 24 |
| **Student level** | | | | | | | | | | |
| Math 2005–06 | 70 | 508.73 | 44.15 | 398 | 636 | 70 | 509.73 | 44.53 | 410 | 609 |
| Math 2007–08 | 70 | 518.51 | 47.68 | 410 | 659 | 70 | 528.10 | 40.32 | 410 | 604 |
| Science 2005–06 | 70 | 368.11 | 33.36 | 270 | 451 | 70 | 371.73 | 32.70 | 230 | 432 |
| Science 2007–08 | 70 | 414.00 | 37.26 | 312 | 532 | 70 | 419.33 | 35.39 | 325 | 491 |
| Female | 70 | 0.41 | 0.50 | 0 | 1 | 70 | 0.41 | 0.50 | 0 | 1 |
| Free/Reduced lunch | 70 | 0.77 | 0.42 | 0 | 1 | 70 | 0.77 | 0.42 | 0 | 1 |
| PLTW enrollment | 70 | 1.00 | 0.00 | 1 | 1 | 70 | 0.00 | 0.00 | 0 | 0 |

[*] The numbers are rounded to 5 significant digits.

*Table 4. Descriptive statistics for teacher and student levels.*

| Test | % Variance at Level 2: Empty Model | % Variance at Level 2: Model With Level 1 Covariates | Reliability of Random Intercepts From Model With Level 1 Covariates |
|---|---|---|---|
| Mathematics | 21.80[*] | 9.48 | 0.291 |
| Science | 30.95 | 8.01 | 0.258 |

[*] The numbers are rounded to 4 significant digits.

*Table 5. Percentage of current year (2007–08) test score variance at teacher level from unconditional model compared with Level 1 covariates and reliability intercepts.*

of the random intercepts at the teacher level for both the unconditional (empty) model and the model with controls for prior achievement and other student characteristics. Table 5 shows that 21.80 percent of the variance in student achievement for mathematics and 30.95 percent of the variance in student achievement for science was at the teacher level without controlling for student prior achievement and student characteristics. However, these percentages decreased to about 9 percent for math and 8 percent for science after controlling for these student factors. This reduction in the percentages of variance suggests that student characteristics explained some of the variance of student achievement in mathematics and science at the teacher level. The reliabilities of the random intercepts at the teacher level for this model are 0.29 for mathematics and 0.26 for science. These results suggest that there is variation at the teacher level and thus multilevel analysis is necessary. The chi-square tests for the random effect of $U_0$ were marginally significant for both tests, indicating that the average level of tenth grade student achievement differs between teachers' classes after controlling for the student characteristics.

### A. *PLTW* Enrollment Effect

Next, we examined the relationship between *PLTW* enrollment and tenth grade student achievement on mathematics and science while controlling for prior student achievement and other student and teacher characteristics. By controlling for prior (eighth grade) performance on the state-wide standardized achievement tests, we are essentially reporting student achievement gains, as it relates to other student and teacher characteristics.

As Table 6 shows, the results are mixed as to whether *PLTW* enrollment is a statistically significant predictor of student achievement in tenth grade after controlling for prior achievement at eighth grade, and both student and teacher characteristics. *PLTW* enrollment was a statistically significant predictor of student achievement in mathematics at the 0.05 alpha level ($p = 0.031$). The model shows that controlling for both student and teacher characteristics, *PLTW* enrollment was associated with an average decrease of 10.76 points in tenth grade math achievement scores. That is, while students in the study showed achievement gains between eighth and tenth grade overall, those enrolled in one or more *PLTW* courses showed significantly smaller gains than students in the comparison group (Figure 1). In addition, we wanted to rule out the possibility that students may not be exhibiting gains because some would have only had a few months of exposure to the *PLTW* curriculum by tenth grade if for example, they had only just started taking pre-college engineering courses. To address this, we examined whether *PLTW* students who had enrolled in more than

| Predictor | Mathematics Coefficient | SE | p | Science Coefficient | SE | p |
|---|---|---|---|---|---|---|
| Intercept | 533.15 | 3.97 | 0.000 | 420.32 | 4.42 | 0.000 |
| Teacher-level predictors | | | | | | |
| Years of experience | –1.02* | 0.32 | 0.004 | –0.29 | 0.35 | 0.410 |
| Student level predictors | | | | | | |
| Female | –7.25 | 4.96 | 0.146 | –2.36 | 4.01 | 0.557 |
| Free/Reduced lunch | –7.05 | 5.92 | 0.236 | –2.85 | 4.89 | 0.560 |
| Prior achievement | 0.69* | 0.06 | 0.000 | 0.81* | 0.06 | 0.000 |
| PLTW | –10.76* | 4.94 | 0.031 | –0.53 | 4.69 | 0.911 |

* Indicates significance at or below the 5 percent level

*Table 6. Conditional models predicting PLTW enrollment.*

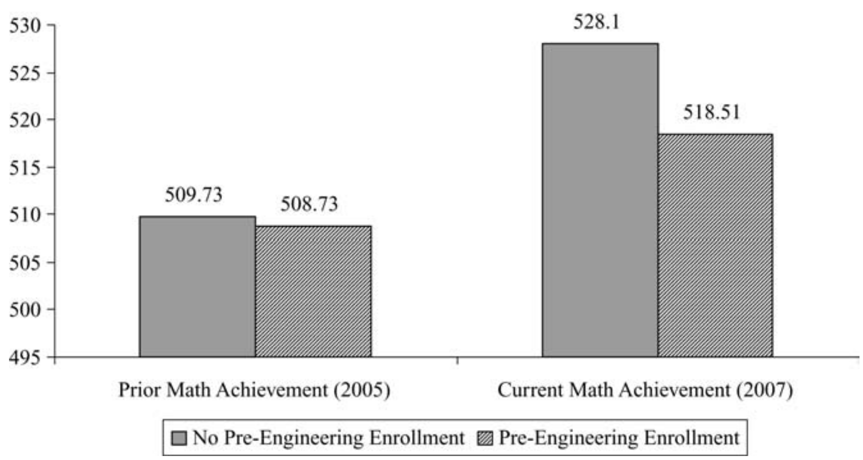



*Figure 1. Prior and current achievement scores of PLTW students and comparison students in mathematics.*

one pre-college engineering course by tenth grade showed different achievement gains than those who enrolled in only one course. In this descriptive analysis we found no differences between these two groups ($p = 0.955$), suggesting that students who had enrolled in multiple *PLTW* courses by the time the state assessment was administered had similar achievements gains to students enrolled in only one *PLTW* course. Since the number of students enrolled in more than one *PLTW* courses ($N = 12$) is very small, we were unable to conduct a meaningful multi-level analysis for students in this group.

The significantly reduced gain in math achievement for *PLTW* students is in contrast to the enriched integration hypothesis that *PLTW* enrollment contributes to higher math achievement. Instead, it gives the most direct support for the model consistent with the adverse integration hypothesis. Since these are correlational findings, we cannot make causal claims that *PLTW* leads to a smaller increase in score, and indeed, there are many other possible accounts that are consistent with this result, as we show in the Discussion section.

We also found that, while students overall gained in science achievement from eighth to tenth grade, those gains were lower for *PLTW* students (Figure 2). However, *PLTW* enrollment was not a statistically significant predictor of achievement scores in science. Again, the pattern was consistent between those who had enrolled in only one *PLTW* course and those who had enrolled in more than one ($p = 0.911$). As with math achievement, this finding also contradicts the enriched integration hypothesis, but now provides more support for the model consistent with the insufficient integration hypothesis that predicts pre-college engineering enrollment is not associated with student achievement. This finding is also addressed in the Discussion section along with the challenges of fostering gains in academic achievement through TE programs.

## V. Discussion and Conclusions

The results of our study do not support the enriched integration hypothesis regarding the relationship between student enrollment in *PLTW* foundation courses and student achievement for science or mathematics. While enriched integration predicts positive gains in math and science associated with *PLTW* enrollment, achievement gains for both assessments were smaller than for students in the comparison group who did not take any *PLTW* courses, though the coefficient was significant only for mathematics. Overall, the evidence is most consistent with the insufficient integration hypothesis in science and adverse integration hypothesis in mathematics. Teacher years of experience did not explain the variation of student achievement across teachers. Whether students had

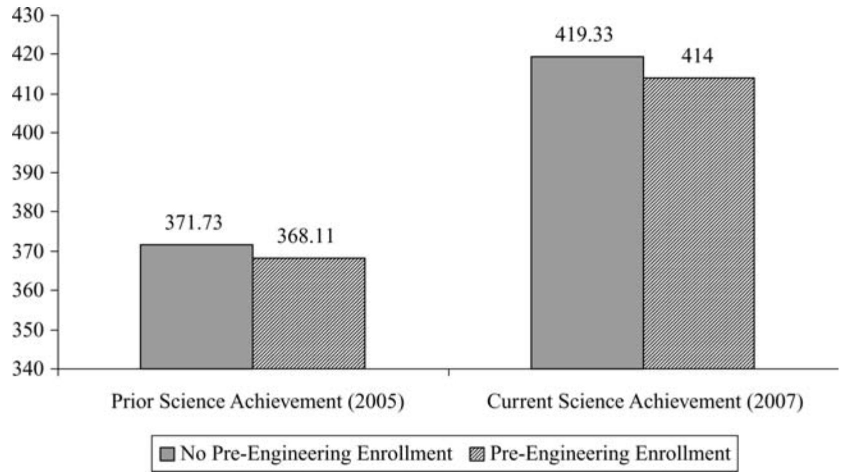



*Figure 2. Prior and current achievement scores of PLTW students and comparison students in science.*

enrolled in one or more than one pre-college engineering course also did not seem to be the main determinant of this set of findings. However, because the sample size for this analysis is relatively small a definitive conclusion about the amount of exposure to the *PLTW* curriculum program cannot be reached. In the following section we consider these findings in the context of the challenges and opportunities that TE programs face in advancing student performance in the academic content areas such as science and mathematics. We then explore some of the possible reasons why positive relationships were not found in science and mathematics achievement. We conclude by addressing some of the limitations of the current study and possible remedies in future research.

**A. General and Technical Education**

Laurillard (2002) makes the distinction between everyday experiences (or practical knowledge) and academic experiences, following Piaget (1929) and Vygotsky (1986). Practical knowledge derives from "first order experiences" in Laurillard's terms (2002, p. 21). As such, it is informal, highly context-bound, and often remains implicit to the members of the communities of practice from which it stems. Although it seems to be the predominant means by which students acquire scientific knowledge outside of school, experience-based science knowledge tends to go unrecognized and is generally under-utilized by classroom teachers (Otero and Nathan, 2008). Experience-based learning provides an account of the kind of learning among professional and social communities that is inclusive in addressing the motivational, affective, and socio-cultural influences of learning.

There is evidence that approaches that draw on experience-based knowledge, such as problem-based learning, can enhance students' problem-solving skills (Barron et al., 1998; Hmelo-Silver, 2004) and improve student learning by emphasizing collaboration, learner-centered and inquiry-based instructions (Kolodner et al., 2003). In a recent study, Mehalik, Doppelt, and Schunn (2008) examined the effectiveness of a related approach, design-based instruction, and compared it to the traditional use of scripted inquiry. The results of this study show that the design-based approach for teaching middle school science is associated with improvement in science achievement, engagement, and retention of science concepts. In a different study, Lachapelle and Cunningham (2007) found that Engineering is Elementary, an engineering curriculum for elementary students, can improve students' knowledge and comprehension of general engineering, technology, and science concepts.

Clearly, there is a growing body of evidence that shows the value of building educational programs that tap into students' experience-based knowledge. However, as an account of all learning modes, experience-based learning may be insufficient for all learning contexts, since "knowledge has to be abstracted, and represented formally to become generalisable and therefore more generally useful" (Laurillard, 2002, p. 16). As Brown and Duguid (1998) note, the danger for situated knowledge is that members of communities of practice may not "know what they know" (p. 23). For knowledge to support reflection, and for it to be used to satisfy standards of scientific rigor, at some point the knowledge must be decontextualized and formalized.

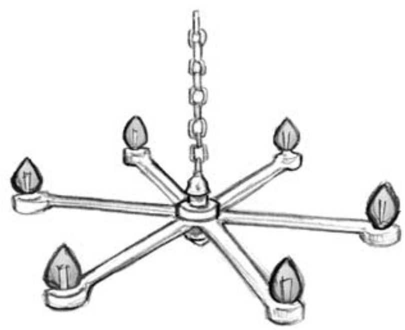
Academic knowledge serves this role. Academic knowledge is derived from our "second order experiences" (Laurillard, 2002, p. 21) because it is made up of descriptions and formal representations of lived experiences (rather than the lived experiences themselves). Examples of this second-order knowledge include theories and domain principles, equations, graphs, and cases, which support abstraction, codification, and verification. In matters of science, public health and safety, and public policy, we expect professionals to employ these rigorous, formal systems, and demand that there are adequate training facilities made available to enable a competent workforce.

One concern in this study is that the state standardized assessments used in our analysis of student achievement may not be aligned with the skills and knowledge that students acquire in *PLTW* courses. In keeping with the framework established by the National Council of Teachers of Mathematics (NCTM), in engineering education one can identify both engineering content and process topics, some of which fall outside of the scope of the assessments used in this study. In terms of content, students are exposed to ideas about scale, perspective, measurement, and the analytical geometry of computer-aided design. They also encounter tool- and software-specific ideas that are central to modern engineering practices. In terms of process, there are numerous opportunities to work collaboratively on design and production tasks, communicate about one's work, as well as the exposure to a wide range of diagrammatic representations. Alignment between what is taught in these courses and what is assessed must be considered as a factor when explaining the negative relationship between *PLTW* course enrollment and achievement in mathematics. For example, Figure 3 shows two

(3A) Which of these ordered pairs is on the graph of $3x - 2y = 12$?

a. (-6, 0)
b. (0, 4)
c. (3, 4)
d. (4, 0)

(3B) A lamp company is designing a light fixture with 6 bulbs. The bulbs are located at the end of six congruent supports as shown below. All the bulbs are evenly spaced around the lamp. What is the approximate measure of the angle ($x$) between each support?



a. 30°
b. 60°
c. 120°
d. 180°

*Figure 3. Examples from the corpus of released items used in the math state assessment.*

example items from the corpus of released items used in the tenth grade state mathematics assessment.

Formal (second-order) descriptions and representations such as that shown in item 3A are aligned with the content typically found in academic math and science courses. In contrast, the *PLTW* curriculum is designed to engage students in hands-on and project-based engineering activities. While these activities may provide students with opportunities to make connections between the skills they are learning in the classroom and application of these skills to technical fields, they may not reflect the content knowledge measured on the state assessments. Because our analysis used standardized achievement scores designed to align most closely with academic course material and content standards, these measures for student learning outcomes may fail to capture other important aspects of student learning related to engineering preparation. Other researchers have also suggested that alternative assessments are needed to demonstrate what students are learning in courses with design-based instruction as is commonly found in engineering and pre-college engineering curricula (Brophy, Klein, Portsmore, and Rogers, 2008).

Misalignment between TE curricula and discipline-specific achievement tests is an important matter to be addressed in pre-college engineering programs. Yet this misalignment between courses and assessments cannot be the whole story. All the students in our data set were subject to the same tests. For example, students enrolled in Algebra, Geometry, Trigonometry/Functions, and other courses in the tenth grade were given the same mathematics assessment. Similarly in science, students enrolled in Integrated Science, Biology, Chemistry, Physics, and so on, all received the same tenth grade science assessment. Controlling for the prior achievement in the eighth grade, differences in student math and science achievements represent students' current ability to perform on these assessments, regardless of the type of math and science courses they enrolled in. Therefore, consistent with the insufficient integration hypothesis, misalignment may explain a *lack* of measurable gain above and beyond students who did not take *PLTW* courses, as with the science achievement outcome. But we also found that the gains in math were significantly lower for *PLTW* students than those in the comparison group. Furthermore, an examination of the range of assessment items shows that some, like those given in 3B (Figure 3), do seem to coincide with an applied technology education program that professes to make math and science relevant to students. This raises broader questions about how math and science ideas are promoted through TE experiences.

### B. *PLTW* Enrollment and Math and Science Achievement

Clearly one of the major challenges facing the new wave of TE programs striving to achieve the ideals called for in the renewal of the Perkins Act and in recent reports like the National Academy of Sciences' *Rising Above the Gathering Storm* (Committee on Science, Engineering, and Public Policy, 2007), is to advance students' knowledge in both traditional TE fields and in traditional academic areas within math and science education. Recently, two studies analyzing pre-college engineering curriculum content and structure have explored the potential of the intended (or idealized) curricula to support academic learning. Although these studies were conducted independently and follow different methodologies, they reached surprisingly similar findings. In one study (Nathan et al., 2008) the investigators specifically examined the absolute and relative frequency with which *PLTW* foundation courses at the high school level addressed the mathematics standards (as obtained from the National Council of Teachers of Mathematics, 2000), and compared this to the mathematics curricula that high school students experience concurrently in their academic courses. The study distinguished between content standards and process standards. Math content standards are the *topics* of math, including: numbers and operations; patterns, functions, and algebra; geometry and spatial sense; and measurement. Math process standards address, in complementary fashion, how math is *performed*, including: methods of data analysis; problem solving; reasoning and proof; communication; connections made across fields of mathematics and applications outside of math; and ways of representing mathematical relationships. The results of this comparative curriculum analysis show that the pre-college engineering *PLTW* curriculum addresses far fewer math content standards than are addressed by the academic math courses taken by the same students. Subsequent analyses of the *PLTW* core curricula show limited occasions where the mathematics concepts that do arise are explicitly integrated with the engineering activities intended for each lesson (Prevost et al., 2009). *PLTW* courses do a much better job addressing process standards, especially problem solving and uses of representations.

In another recent study, Welty et al. (2008) analyzed 22 pre-K-12 engineering curricula, including nine high school programs. The analysis explored the mission and goals of each curriculum; the presence of engineering concepts; and the treatment of mathematics, science, and technology. The investigators offer only preliminary findings at this point. However, their remarks to date are most striking about the shallow role of mathematics across the corpus of curricula. In findings that echo the Nathan et al. (2008) study of *PLTW*, Welty and colleagues lament "the noticeably thin presence of mathematics" in K-12 engineering curricula (p. 10). They explained, "Most of the mathematics in engineering curricula simply involved taking measurements and gathering, organizing, and presenting data. Very little attention was given to using mathematics to solve for unknowns. Furthermore, little attention was given to the power of mathematical models in engineering design" (Welty et al., 2008, p. 9). For example, the investigators found that modeling tended to involve the use of student-made physical artifacts and graphical representations during the design process, but seldom involved the formulation of analytical models, such as algebraic equations, which would support data analysis and prediction.

Interestingly, the recent Carnegie report examining undergraduate engineering programs in the U.S. indicates that "although engineering schools aim to prepare students for the profession, they are heavily influenced by academic traditions that do not always support the profession's needs…primarily focused on the acquisition of technical knowledge" (Sheppard et al., 2008, p. 4). Findings from the studies above suggest that while students in K-16 are not being adequately prepared for future careers in engineering, these programs emphasize the academic forms of science and mathematics.

At the secondary level, the poor integration of math and science in pre-college engineering curricula deprives students of opportunities to make connections and apply the mathematical and scientific theory they have learned in these academic courses to engineering contexts. It is possible that teacher beliefs about student learning play an important role in shaping the order and sequence of materials presented in the classroom. For example, Nathan and Koedinger (2000a) found that high school teachers and math education researchers tend to believe that students will do better on abstract algebra equations (theory) than on algebra story problems (applied contexts). Teachers' and researchers' rankings of problems by the predicted difficulty for students also differed from the actual performance of high school students who, in reality, performed better on story problems than equations, even though the items were constructed to control for the underlying quantitative structure. The results of this study suggest that teachers generally hold a symbol precedence view (SPV) of cognitive development—that is, children will learn the abstractions or theory before (and as a precursor to) the applied or contextualized tasks-despite student performance data to the contrary.

In a related study, Nathan and Koedinger (200b) found that while high school teachers hold the SPV, middle school teachers do not, and they are significantly less likely to rank equations as easier than story problems. These results suggest that Expert Blind Spot is at play: high school teachers who have greater content knowledge, may be worse at predicting the students' actual developmental trajectory (what's easy and difficult for students) than middle school teachers, who actually have less content knowledge. Similar findings were reported when comparing pre-service teachers with high versus low levels of math expertise (i.e., math and science majors versus non-math and non-science majors). Those with greater expertise showed the SPV and inaccurately predicted student difficulty on equations and story problems, while those with less content knowledge showed much better predictions of student performance (Nathan and Petrosino, 2003).

Though Expert Blind Spot is a concern, there is also evidence that providing the proper training to teachers can lead to positive outcomes in student performance on standardized tests. A recent experimental study (Stone, Alfred, and Pearson, 2008) examined the effects of a yearlong, teacher professional development program that focused on the integration of mathematical concepts in TE courses (though the study did not include pre-college engineering). The results show that students whose teachers received the professional development training on math-enhanced lessons ($N$ = 59 teachers) performed significantly better on standardized tests assessing mathematics ability, than the control students, whose teachers ($N$ = 78) did not participate in the professional development training, with no concomitant loss in performance on TE measures.

While the pedagogical and cognitive issues surrounding the integration of math and science in TE courses are not fully understood, the lack of explicit connections made between academic and pre-college engineering courses stands to reinforce the differences in skills and knowledge valued in TE compared to those in college preparatory education. It may feed attitudes counter to some measures of math and science achievement. In the case of using electronic technology, for example, students can come to expect that the technology will or should do the thinking for them, which may be especially problematic for students already exhibiting low math achievement (Rittle-Johnson and Kmicikewycz, 2008). This can create a climate within which TE courses may do little to contribute to gains in math and science assessments, and may even foster declines in achievement, while still making strides in TE.

This is also problematic given the cognitive science research that emphasizes the importance of explicit integration of concepts for successful transfer of knowledge (Bransford, Brown, and Cocking, 2000). One of the considerations of engineering curricula, particularly at the secondary and post-secondary levels, is the conceptual connections made to science and mathematics. Yet, it is not enough to simply document how many math or science standards are mentioned, one should also consider the degree to which these connections are made explicit to students, so that they recognize the connections and draw on them when faced with novel problems in the future. This is because transfer improves when knowledge is organized around central, abstract concepts (Judd, 1908; Nathan et al., 2009; Streveler et al., 2008), and when one's conceptual knowledge is explicitly integrated with the application area, engaging both cognitive and metacognitive resources in order to consciously relate new ideas to previous knowledge (Bransford and Schwartz, 1999; Palincsar and Brown, 1984; Schoenfeld, 1985).

Drawing on this view of transfer, one curriculum analysis study looked at whether math concepts and skills were *explicitly integrated* in the three *PLTW* foundations courses, or remained implicitly embedded in the tools and activities. Explicit integration was defined as those cases when math principles, laws, or formulas were overtly identified, and it was discussed or demonstrated how the math could be used to carry out or understand the engineering task at hand (Prevost et al., 2009). This analysis revealed that, while many math standards were touched on across the curriculum, integration between the engineering activities and the mathematical procedures and skills were seldom explicit, and this was particularly the case in the entry-level foundation course, Introduction to Engineering Design.

**C. Limitations and Future Work**

This paper has several limitations that we would like to point out in hopes that they can be addressed in future research. First, because of our high standard on complete data and need for all students to have achievement information at two points in time, the results are based on a relatively small sample, which necessarily yield tentative conclusions about the relationship between *PLTW* foundation courses and student achievement in mathematics and science. We plan to collect data on student achievement and course enrollment in subsequent years. This will allow us to replicate the results with a larger sample size and provide stronger evidence for conclusions about the relationship between *PLTW* course enrollment and student achievement. Second, the district that we studied provided a limited number of specialized *PLTW* courses such as Aerospace Engineering, Biotechnical Engineering, Civil Engineering and Architecture, and Computer Integrated Manufacturing. This selection of course offerings resulted in the limited data that could be used in our analysis. For example, it is possible that Aerospace Engineering and Biotechnical Engineering courses provide richer science content—one that may result in increasing science achievement for *PLTW* students enrolled in these courses. However, without the adequate data, it is uncertain whether students enrolled in these courses can benefit from the explicit connections to scientific concepts. Third, since the assessments were administered in the tenth grade (November), students who enrolled in *PLTW* foundation courses in the ninth grade may only have exposure to the curriculum for a little over a year. Therefore, it is uncertain whether longer exposure to *PLTW* course (i.e., eleventh and twelfth grade years) would yield improvement in mathematics and science. Unfortunately, the current schedule of assessments here, as in many other states, does not provide us with that information for future analysis. The development of assessment instruments that can be given later on in one's high school program can assist with this, but they must be given broadly to the student body to support experimental analyses of this sort. A final limitation of the study is that we assume that the amount of exposure to math and science instruction and the degree of integration of these concepts and skills with engineering activities will predict students' learning and future transfer. However, we currently collect no direct measures of cognitive engagement (Corno and Mandinach, 1983) during the learning process. While engagement is difficult to measure objectively, future studies directed toward this would ultimately provide a more direct account of students' engineering learning experiences.

This study also generated a number of plausible explanations that go beyond the current data, about why math achievement of *PLTW* students would show a smaller increase. We identify several potentially fruitful paths to further explore these issues. Currently, we are conducting observational studies of the learning and instructional practices in math, science, and *PLTW* classrooms (e.g., Nathan et al., 2009) that should provide in-depth information about the different instructional qualities that pervade the TE and academic learning settings. We also see the need to conduct more tightly controlled, "think aloud" studies of *PLTW* and non-*PLTW* students solving academically oriented math problems of the sort that make up the bulk of standardized state assessments. This approach can reveal the cognitive processes exhibited by students during problem solving and provide further insights about the opportunities and challenges for integrating math and science knowledge in pre-college engineering curricula.

**D. Conclusions**

The pool of engineers in the U.S. is neither large enough nor diverse enough to meet the needs of a growing, high-tech economy. To develop methods to create a broader and more diverse pool of engineers in the U.S., the National Research Council (2007) calls for educational leaders to optimize its knowledge-based resources and energize the STEM career pipeline. The integration of mathematics, science, and TE has become central to TE policy and high school reform efforts that strive to prepare graduates for both college and career opportunities in engineering. While this poses an enormous challenge, innovative pre-college engineering curricula such as *Project Lead the Way*, informed by research that examines their academic impacts, have the potential to deliver a broadly inclusive technical workforce as well as citizenry who are able to participate in the emerging technological and globalized society.

## Acknowledgment

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