Comparing Mathematics and Science Achievement of Students from Schools with PLTW versus Schools without PLTW

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***Abstract*—Project Lead the Way (PLTW) has been developed to provide a rigorous engineering curriculum that allows high school students to learn about advanced engineering concepts and their application in various STEM-related subjects. The present study was designed to examine the effectiveness of PLTW curriculum on high school students' mathematics and science achievement. Mathematics and science scores of students attending PLTW schools and students attending non-PLTW schools were compared using student data gathered from the 2016 State of Texas Assessments of Academic Readiness (STARR). In the present study, T-STEM schools were removed to avoid the impact of other STEM curricula on participants' mathematics and science achievement. Scores on the mathematics STARR test were gathered from 804 students in PLTW schools and 805 students in non-PLTW schools, and scores from the science STARR test were gathered from 800 students in PLTW schools and 800 students in non-PLTW schools. The results indicated that the mean of students' mathematics achievement in PLTW schools was higher than the mean of students' mathematics achievement in non-PLTW schools (*d*=0.400, 95% *CI*=[0.300, 0.498]). The mean of students' science achievement in PLTW schools was higher than the mean of students' science achievement in non-PLTW schools (*d*=0.197, 95% *CI*=[0.099, 0.295]).**

Keywords—Project Lead the Way (PLTW), Mathematics, Science, Academic achievement, State of Texas Assessments of Academic Readiness (STAAR)

I. Literature Review

In the 21st century, the demand for professionals in science, technology, engineering, and mathematics (STEM) fields has increased as the number of STEM-related fields and occupations has grown. Many of the jobs emerging in the growing STEM sector require extensive science and mathematics knowledge and 21st century technical skills. Therefore, developing strategies and curricula to improve students' STEM readiness has become a critical issue within the field of educational research. This need to improve STEM readiness is of particular concern for the United States (U.S.), whose students have fallen behind those of other developed countries in their mathematics and science performance [1; 2; 3]. While this finding does not conclusively indicate that U.S. students' performance in STEM disciplines is poor, it does raise concerns about their level of academic performance as poor performance in STEM disciplines during high school may deter students from pursuing STEM-related majors and career paths [4]. Accordingly, incorporating STEM readiness strategies and curricula in U.S. high schools is essential to improve student performance in STEM disciplines, which may bolster their interest in pursuing STEM-related majors and career paths and equip them with the knowledge and skills to successfully meet the growing demand for STEM professionals. In response to this need, an increasing number of schools that include STEM-integrated curriculum have been established.

The use of STEM curricula situated within an authentic learning experience has produced many positive results and success in improving students' academic achievement and affective development. Researchers have found that the use of STEM curricula can improve students' science and mathematics achievement [5; 6] and narrow achievement gaps between students of different socioeconomic statuses (SES), ethnicities, and genders [6; 7; 8]. The STEM learning opportunities provided through the use of STEM curricula have fostered critical thinking, analysis, and collaboration where students were able to integrate the concepts into authentic

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learning experiences situated in real-world contexts [6; 7; 9]. Students were engaged in the learning process because they were able to see a meaningful connection between their learning and real-life [10]. This engagement developed students' motivation, interest, positive attitude, and persistence toward STEM disciplines [11; 12; 13; 14]. Therefore, the integration of STEM curricula has been encouraged in K-12 schools to foster STEM skills and interest in STEM disciplines and could be a hope for better preparing and supplying the future STEM workforce.

Project Lead the Way (PLTW), one of the popular STEM-related curricula that contains an emphasis in engineering, has been implemented in numerous schools to improve students' STEM readiness. PLTW is one of the STEM curricula and professional development programs that have been created to increase K-12 students' interest in STEM fields [15]. The PLTW curriculum was established in 1986 by Richard Blais and transformed into an engineering program for students to learn basic engineering skills [16]. With support from the Charitable Leadership Foundation, the program later developed into a more established engineering curriculum for high school students to learn engineering concepts in conjunction with broader STEM-related concepts in mathematics, science, and other subjects through project-based learning [16; 17]. PLTW curriculum is primarily used as a tool to increase students' problem-solving skills, innovative skills, and critical-thinking ability through learning in an engineering-based context [18]. Providing students with opportunities to develop such skills is critical for the U.S. to increase the overall STEM proficiency of its future workforce. For this reason, many schools have incorporated PLTW curriculum either to complement their existing curriculum or to function as their core curriculum [18]. PLTW has been the largest nonprofit provider of STEM programs, providing 6,000 PLTW programs to more than 5,000 K-12 teachers in all 50 states and the District of Colombia [19]. Thus, as a provider of STEM programs and curriculum, PTLW has an extensive influence within the realm of STEM education.

Much like the benefits found in implementing various forms of STEM curricula situated within authentic learning experiences, PLTW has been shown to positively impact students' academic performance and affective engagement in STEM subjects as well as their motivation to engage in STEM-related disciplines. In PLTW-integrated classrooms, students have the opportunity to practice efficient problem solving, which is a necessary skill required within numerous STEM-related careers [20]. Teachers who use PLTW provide their students with vital interdisciplinary experience and knowledge that encompasses concepts in engineering, technology, and other subjects such as science and mathematics [16]. Research indicates that these rich experiences that foster high levels of engagement through PLTW curriculum led students to improve their academic performance [15; 16; 17]. Furthermore, the performance gaps between students from different genders, ethnicities, and SES were decreased in the schools that implemented PLTW curriculum [19]. In addition, it was claimed that students who attended schools with PLTW curriculum were more likely to choose and retain STEM-related majors during their post-secondary education [16] because of their interest toward STEM-related disciplines [15; 17; 20]. These positive findings regarding the use of PLTW curriculum suggest that incorporating PLTW in classrooms could be a viable solution for addressing many of the problems related to STEM education and the STEM workforce in the United States.

Despite the wide-spread use of PLTW in numerous schools, and the documented benefits of its use, few researchers have investigated the effectiveness of PLTW curriculum in comparison to traditional, non-STEM high school curricula using large-scale standardized assessments administered over the course of several years. Therefore, to determine the effects of PLTW curriculum, we posed the following research question: Is there a statistically significant difference between students who attended schools implementing PLTW and students who attended schools implementing a non-STEM curriculum (non-PLTW) on their mathematics and science State of Texas Assessments of Academic Readiness (STAAR) scores?

II. Methodology

We examined the mathematics and science achievement of high school students in PLTW schools and non-PLTW schools using the State of Texas Assessments of Academic Readiness (STAAR) results from the 2016 academic year. Demographic information and STARR data for both students who attended the schools implementing PLTW curriculum and those who attended the schools that implemented non-STEM curriculum (non-PLTW) were obtained from the Texas Education Agency (TEA). Using this data, we first categorized schools by type. Inclusive stand-alone Texas STEM (T- STEM) schools were excluded because PLTW curriculum and other types of STEM curriculum have similar features in their prescribed teaching and learning strategies. Therefore, we removed T-STEM schools from our analysis to ensure that participants' mathematics and science achievement were not influenced by other STEM curricula. After excluding the STAAR scores of students attending T-STEM schools, the remaining mathematics and science achievement data from the 2016 STAAR tests were categorized into one of two types: *'PLTW schools'* that implemented the PLTW curriculum and did not use any other STEM curriculum and *'non-PLTW schools'* that did not implement PLTW curriculum or any other STEM curriculum. Based on this categorization criteria, non-PLTW schools were considered schools that implemented traditional curriculum.

Once each school was categorized as PLTW or non-PLTW, participants for the study were selected from these schools using random sampling by their participation in either a PLTW or non-PLTW school. The final 2016 mathematics STAAR data sample consisted of scores for 1609 students (PLTW schools, n=804 and non-PLTW schools, n=805). The final 2016 science STAAR data sample consisted of scores for 1600 students (PLTW schools, n=800 and non-PLTW schools, n=800. Table 1 contains an outline of the demographics for students participating in this study.

TABLE I. DEMOGRAPHICS OF PARTICIPANTS

	Mathematics		Science	
	non-PLTW	***PLTW***	***non-PLTW***	***PLTW***
Gender				
Female	275(34.2%)	334(41.5%)	416(52.0%)	380(47.5%)
Male	530(65.8%)	470(58.5%)	384(48.0%)	420(52.5%)
Ethnicity				
Asian	2(0.2%)	1(0.1%)	27(3.4%)	34(4.3%)
African	193(24.0%)	115(14.3%)	77(9.6%)	61(7.6%)
American	126(15.7%)	100(12.4%)	382(47.8%)	350(43.8%)
Caucasian	470(58.4%)	580(72.1%)	313(39.1%)	355(44.4%)
Hispanic	14(1.7%)	8(1.0%)	1(0.1%)	-
Others				
Grade				
8^{th}	6(0.7%)	1(0.1%)	13(1.6%)	-
9^{th}	664(82.5%)	682(84.8%)	722(90.3%)	777(97.1%)
10^{th}	109(13.5%)	99(12.3%)	61(7.6%)	23(2.9%)
11^{th}	24(3.0%)	18(2.2%)	11(0.4%)	-
12^{th}	2(0.2%)	4(0.5%)	1(0.1%)	-
At-risk				
Yes(1)	737(91.6%)	775(96.4%)	324(40.5%)	324(40.5%)
No(0)	66(8.2%)	29(3.6%)	476(59.5%)	476(59.5%)
Missing	2(0.2%)	-	-	-
Total	805	804	800	800

SPSS 24 was used to conduct statistical analyses of the data. To determine the mean differences of students' STAAR mathematics and science scores by school type (PLTW schools vs. non-PLTW schools), an independent *t*-test was used. Descriptive statistics including 95% Confidence Intervals (*CI*) and *t*-values with *p*-values were reported.

III. RESULTS

Descriptive statistics of mathematics and science regarding the school types (PLTW & non-PLTW schools) are presented in Table 2. Means, standard deviations (*SD*), and confidence intervals (lower and upper limits) were calculated for both the mathematics and science STAAR scores for each PLTW and non-PLTW school. There was a gap between PLTW and non-PLTW schools in the total mean of both their mathematics and science scores. In terms of mathematics, the total mean score of students from PLTW schools (M=2721.39) was higher than the total mean score of students from non-PLTW schools (M=2327.32). The total mean score of science in PLTW schools (M=4259.22) was also higher than the total mean score of non-PLTW schools (M=4127.95).

TABLE II. DESCRIPTIVE STATISTICS

Subject	School Type	*Mean*	*SD*	*95% CI*
Mathematics	Non-PLTW	2327.32	1007.793	[2257.32, 2397.32]
	PLTW	2721.39	965.730	[2654.39, 2788.39]
Science	Non-PLTW	4127.95	745.425	[4075.95, 4179.95]
	PLTW	4259.22	577.651	[4219.22, 4299.22]

The independent *t*-test was conducted using the mathematics and science scores of the participants from the PLTW schools and non-PLTW schools to examine whether there were statistically significant mean differences between students in terms of PLTW and non-PLTW. Results from the analysis revealed that the difference between students' mathematics achievement by PLTW and non-PLTW schools was statistically significant (t=-8.008, df=1607, p<.001, see Fig. 1). The mean of students' mathematics achievement in PLTW schools was higher than the mean of students' mathematics achievement in non-PLTW schools. The Cohen's *d* effect size for this difference was 0.400, and the 95% confidence interval associated with this effect size was [0.300, 0.498]. The difference between students' science achievement by PLTW and non-PLTW schools was statistically significant (t=-3.93, df=1598, p<.001, see Fig. 2). The mean of students' science achievement in PLTW schools was higher than the mean of students' science achievement in non-PLTW schools. The Cohen's *d* effect size for this difference was 0.197, and the 95% confidence interval associated with this effect size was [0.099, 0.295].

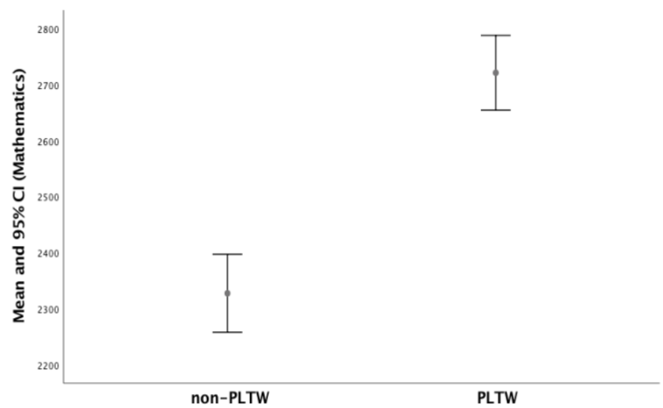

Fig. 1. Means and 95% Confidence Intervals of mathematics scores.

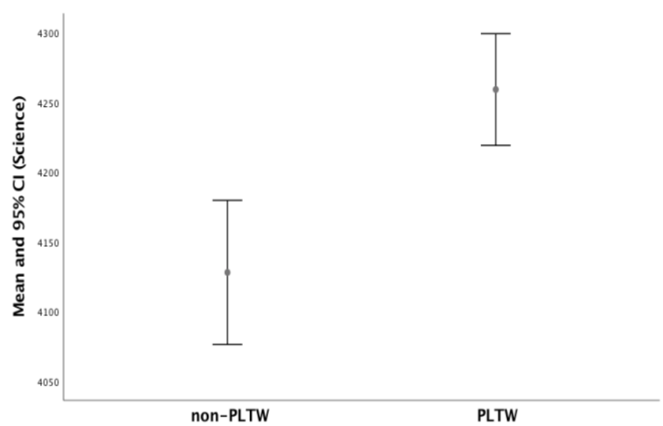

Fig. 2. Means and 95% Confidence Intervals of science scores.

IV. Discussion

The effectiveness of PLTW curriculum for developing high school students' mathematics and science achievement was investigated. Prior studies have focused on the effectiveness of PLTW as compared to other STEM-based curricula used at STEM designated high schools (e.g., [18; 21; 22]). The results from previous studies indicated that PLTW provided meaningful benefits; however, what was absent from those prior studies was whether or not PLTW could provide a benefit over a traditional, non-STEM high school curriculum. This carefully designed study isolated PLTW from other traditional high school curriculum options and then compared the results of the students in schools that used PLTW curriculum to those of students in schools using other high school curriculum options on a state mandated test. In choosing an outcome measure, it might have been more effective to use a test designed to clearly determine the knowledge learned in PLTW and then to compare that to knowledge learned through the traditional high school curriculum. However, regardless of what students learn through the use of PLTW curriculum or non-PLTW curriculum, both curricular options must achieve the same goals to ensure that students have the option to enter a post-secondary STEM academic and career pathway. Each curricular option must prepare students with the knowledge and skills to receive adequate scores on a high stakes test. Thus, the STARR test was used to measure the effectiveness of PLTW and non-PLTW curriculum. The students in schools in which PLTW was implemented demonstrated greater achievement even though the demographic variables of the PLTW group were similar to those of the non-PLTW group. The large effect sizes, by educational standards, are indicative that the results are likely robust. However, the robustness could be due to the study design, which was random selection and not random assignment, meaning the magnitude of the effect could be greater or smaller than evidenced here.

The very small obtained *p*-value is likely confounded because of the large sample size, and is therefore, very small because of the large sample size. The mitigating factor, however, is the confidence intervals, which demonstrate a clear differentiation among the groups that favor the PLTW experience, and the relatively narrow intervals indicating the preciseness of the point estimates for both groups. It is interesting that the mathematics scores were more precise in both the PLTW and non-PLTW group than the science scores for both groups. This raises an important question about whether or not PLTW may contextualize mathematics in a more applied way, thereby providing an added benefit to learning mathematics. To expound on this idea, the state mandated mathematics test contains highly situated questions that necessitate understanding of a situation, in which a student must first interpret what is going on in word problems and then solve them. However, traditional curriculum in high school mathematics classes is often centralized around solving problems that are directly presented as an equation. Because PLTW uses a STEM-based curriculum instructional strategy that incorporates authentic learning experiences, students encounter similar complex mathematics that they would find in traditional mathematics classrooms, but in application [6; 7; 9]. The type of experiences they encounter in PLTW require them to conceptualize the problem, often pose it themselves once they clearly articulate it, and then solve the problem. It could be hypothesized that this is beneficial to mathematics learning and would result in lower standardized measurement error (narrower 95% confidence intervals). Our results support this hypothesis, indicating that PLTW curriculum may offer an advantage over the regular curriculum for our sample.

It would be beneficial to the field of STEM education if it were possible to directly examine the degree to which PLTW does provide an advantage for demonstrating to students the contexts and scenarios in which the mathematics they are learning can be applied and are used in real world application. Although the results of this kind of investigation would be low stakes, they would help provide important information about whether or not highly contextualized and experiential situations are essential for developing deep mathematical understandings. It is possible that the application problems contrived in traditional mathematics are sufficient and achieve the same end result.

Student performance in science between those attending PLTW and non-PLTW schools was markedly different in the preciseness of the point estimates. While it would not be helpful to argue that the observed differences between the *CI*s were actually important, it is essential for the field to understand influential characteristics of data found in observations so that future research can control for possible moderators. One possible factor influencing the variance found in the scores in the present study relates to the STARR test. The STARR test that students complete to measure their level of science knowledge and comprehension is not administered at each grade level in high school. In addition, once students begin taking specialized science instruction, they are no longer receiving general science instruction on which the science STARR test is based. Therefore, a student who is a high achiever may take biology in 8^{th} grade, chemistry in 9^{th} grade, physics in 10^{th}, and anatomy and physiology, ecology, or some other science elective in 11^{th} and 12^{th} grade, or no science at all. Regardless, general science knowledge is still tested during the exit level STARR test in 11^{th} grade. Prior to taking the exit level test in 11^{th} grade, students' last encounter with the general science test is in 7^{th} grade; this discontinuity in exposure to and assessment of general science knowledge could present issues for students whose knowledge in this area could be stale or forgotten altogether during this interval of time. These gaps in knowledge could result in the observed within-group variation because the variation is similar for both the PLTW and non-PLTW groups in science. When comparing the variance of mathematics and science in this study, one is tempted to believe that because both are from the same samples of nearly exactly the same size, the variance should be identical. However, mathematics is more convergent than science, meaning that skills in subsequently more advanced mathematics are built on previously developed and more basic ones, which means that those initial skills, from necessity, are revisited and more likely to be fresh when assessed during the exit level STARR test. Finally, one potential lurking variable impacting the variation of the science scores could be language. The science test necessitates a greater degree of language across a broader range of meanings. If this is the case, it can account for why the variation for each of the science groups are nearly identical yet different from mathematics. Because of the large sample size and the random selection process, we do not believe that these observed differences are due to chance; instead, they appear to be the outcomes of true characteristics worthy of investigation.

Some demographic variables are both noteworthy and important to examine. There is too little understanding of how STEM curricula impacts critical subpopulations. For example, female, at-risk, and other underserved student populations are nearly absent in the extant literature. However, due to the sampling process, it was not possible to address our interest in how PLTW performed compared to traditional curriculum (non-PLTW) in regard to underserved subpopulations. Our random selection process did not yield exactly similar subpopulations in terms of underserved students versus traditionally advantaged students (e.g., White, male, etc.), and had we then balanced for the subpopulations, we would have obfuscated the random selection process in favor of randomized block design, which would have curtailed our total possible sample, thereby restricting our ability to make claims about the impact of PLTW when compared to traditional curriculum.

We believe that this study offers unique insights because there has been no study to date in which researchers have directly and explicitly compared the traditional public school curriculum to PLTW. Having students prepared for rigorous post-secondary STEM-related coursework should be a paramount concern [10]. College-matriculating and post-secondary students who lack essential mathematics and science knowledge and skills exit the engineering disciplines track before ever taking a meaningful engineering course [18; 21]. Therefore, understanding the impact of these types of engineering curriculum on students' mathematics and science achievement, absent any other substitute for an engineering curriculum, may help to provide important consumer warnings before implementing these curricula. The results of this study lay the groundwork for researchers and educators alike to make wise recommendations and to set reasonable expectations for the PLTW curriculum and its promise for improving students' opportunities for success in post-secondary STEM majors.

REFERENCES

[1] H. L. Fleischman, P. J. Hopstock, M. P. Pelczar, B. E. Shelley, and H. Xie, "Highlights from PISA 2009: Performance of U.S. 15-year-old students in reading, mathematics, and science literacy in an international context (NCES 2011-004)," ED513640, US Dept. Edu., Washington, DC, 2010.

[2] P. Gonzales, J. C. Guzman, L. Partelow, E. Pahlke, L. Jocelyn, D. Kastberg, and T. Williams, "Highlights from the Trends in International Mathematics and Scince Study (TIMSS) 2003 (NCES 2005-005).," ED483080, Dept. Edu., Washington, DC, 2004.

[3] U.S. Department of Education, A nation accountable: Twenty-five years after a nation at risk. Washington, DC: Author, 2015.

[4] Y. Torlakson, "INNOVATE: A blueprint for science, technology, engineering, and mathematics in California public education." Dublin, CA: Californians Dedicated to Education Foundation, 2014.

[5] R. M. Capraro, M. M. Capraro, and J. R. Morgan, Eds. "STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach", 2nd ed., Rotterdam, The Netherlands, Sense Publishers, 2013.

[6] S. Olson and J. Labov, STEM learning is everywhere: Summary of a convocation on building learning systems. Washington, DC: The National Academies Press, 2014.

[7] M. Sanders. "STEM, STEM education, STEM mania," *The Tech. Teach.*, vol. 68, no. 4, pp. 20-26, 2009.

[8] M. Yilmaz, J. Ren, S. Custer, and J. Coleman, "Hands-on summer camp to attract K-12 students to engineering fields," *IEEE Transactions on Education*, vol. 53, no.1, pp. 144-151, 2010.

[9] E. Ostler. 21st century STEM education: A tactical model for long-range success. *Internatl. J. Appl. Sci. and Tech.*, vol. 2, no. 1, pp. 28-33, 2012.

[10] National Research Council, "Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics," Committee on Highly Successful Science Programs for K-12 Science Education, Washington, DC: The National Academies Press, 2011.

[11] R. M. Capraro, R. and S. W. Slough, "Why PBL? Why STEM? Why now? An introduction to project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach," In R. M. Capraro, M. M. Capraro & J. Morgan (Eds.), *STEM Project-based learning: An integrated science technology engineering and mathematics (STEM) approach* (pp. 1-6). Rotterdam, Netherlands: Sense, 2013

[12] M. Honey, G. Pearson, and H. Schweingruber, Eds. "*STEM integration in K-12 education: Status, prospects, and an agenda for research,*" Washington, D.C.: National Academies Press, 2014.

[13] L. Springer, M. E. Stanne, and S. S. Donovan "Effects of small-group learning on undergraduates in science, mathematics, engineering and technology: A meta-analysis," *Rev. Edu. Res.*, vol. 69, no. 1, pp. 21–51, 1999.

[14] K. H. Tseng, C. C. Chang, S. J. Lou, and W. P. Chen. "Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment," *Internat. J. Tech. and Design Edu.*, vol. 23, no. 1, pp. 87-102, 2013.

[15] G. Adelson and R. R. Blais, "Project Lead The Way-A model program for initiating, funding and maintaining a successful pre-engineering program in the nation's high schools," in Frontiers in Edu. Conf., FIE'98. 28th Annual, vol. 3, pp. 1161-1165, 1998.

[16] G. Bottoms and K. Anthony, "Project Lead the Way: A pre-engineering curriculum that works," Southern Regional Educational Board, Atlanta, GA, USA, 2005.

[17] B. R. Martin, "Factors influencing the self-efficacy of black high school students enrolled in PLTW pre-engineering courses," Ph.D. dissertation, Capella Univ., 2011.

[18] A. Bicer, P. Boedeker, M. Kopparla, R. M. Capraro, M. M. Capraro, "Comparing students' mathematics achievement by their school types: Inclusive STEM schools that implemented PLTW curriculum with inclusive STEM schools that did not implement PLTW," in Frontiers in Edu. Conference, 2015. FIE'15. pp. 1-5.

[19] Project Lead The Way, "Our impact," 2009, [Online] Available: https://www.pltw.org/about-us/our-impact

[20] T. R. Kelley, "Cognitive processes of students participating in engineering-focused design instruction," *J. Tech. Edu.*, vol. 19, no. 2, pp. 50-64, 2008.

[21] N. A. Tran and M. J. Nathan, "Pre-college engineering studies: An investigation of the relationship between pre-college engineering studies and student achievement in science and mathematics," *J. of Engineering Edu.*, vol. 99, no. 2, 143-157, 2010.

[22] J. P. Van Overschelde, "Project lead the way students more prepared for higher education," *Amer. J. of Engineering Edu.*, vol. 4, no. 1, pp. 1-12, 2013.