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Research, Evaluation and Policy Analysis • Wisconsin Careers • Careers Conference • Career Learning Resources

# Engineering the Math Performance Gap

## Summary

The next generation of engineers, technicians, and community-engaged citizens will need a deep understanding of science and engineering processes to solve global challenges, such as making solar energy economical, securing cyberspace, and engineering better medicines. Recently introduced high school engineering courses are providing students with opportunities to learn how real-world problems are solved using mathematics and scientific principles, and to examine various careers in the science, technology, engineering and mathematics (STEM) fields directly. In this case study of an engineering charter school located within a Wisconsin comprehensive high school, the non-experimental data for school year 2007-08 revealed that seniors completing engineering courses, when compared to all other seniors not enrolling in engineering courses, were significantly more likely to:

- Receive higher composite ACT scores (26.7 compared to 23.1)
- Attain higher ACT math scores (27.1 compared to 23.2)
- Complete about the same amount of math and science credits in high school (~3.2 to 3.4 credits)
- Report being involved in career exploration, including talking with adults about career goals and participating in school experiences that help them clearly define career goals.

These important findings offer preliminary, proof-of-concept evidence that overall college readiness, and mathematics proficiency in particular, can be raised through engineering and technology education programs.

*Addressing the global Grand Engineering Challenges will require higher mathematical competence in the 21st century.*

New and unprecedented standards for mathematical and computation literacy have emerged for the nation's workforce. Generated by the science-intensive and digitally driven global economy, today's careers in health science, engineering, value added manufacturing, and nano-fabrication require advanced mathematics. The importance of mathematical and computational competency to the nation's future can be found in the National Academy of Engineering's recently identified 14 grand challenges—societal challenges which await innovative engineering solutions. *Restoring and improving the nation's urban infrastructure* is one of the Grand Challenges and the National Academy[2] describes it in vivid terms:

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> The urban infrastructure is the combination of fundamental systems that support a community, region, or country. It includes everything from water and sewer systems to road and rail networks to the national power and natural gas grids. Perhaps there will be a hydrogen grid in the future as well. . . . Good design and advanced materials can improve transportation and energy, water, and waste systems, and also create more sustainable urban environments. Engineers of the 21st century face the formidable challenge of modernizing the fundamental structures that support civilization. . . . The problem is particularly acute in urban areas, where growing populations stress society's support systems, and natural disasters, accidents, and terrorist attacks threaten infrastructure safety and security. And urban infrastructure is not just a U.S. issue; special challenges are posed by the problems of megacities, with populations exceeding 10 million, which are found mostly in Asia. In many parts of the world, basic infrastructure needs are still problematic, and engineers will be challenged to economically provide such services more broadly.[1]

Closer to home, the Wisconsin Department of Workforce Development estimates that through 2016 some of the fastest growing science, engineering and technical careers are integral to addressing Wisconsin's urban and rural infrastructure challenges. Each of the following careers requires both postsecondary education, as well as mathematical competence which includes algebra, geometry, calculus, statistics, and the application of this knowledge and skills to the solution of engineering problems.

| Selected Science, Engineering and Technical Careers[2] | Average Annual WI Openings through 2016 | Percent Growth | Median Salary 2007 |
|---|---|---|---|
| Computer Systems Analyst | 520 | 21 | 64,000 |
| Industrial Engineer | 240 | 20 | 64,000 |
| Construction Manager | 180 | 16 | 79,000 |
| Civil Engineer | 150 | 9 | 62,900 |
| Surveyor | 60 | 11 | 48,600 |
| Biological Technician | 50 | 13 | 34,400 |

*Fifteen of the sixteen U.S. career clusters require high school mathematics at the level of advanced algebra or beyond.*

On the national landscape, 15 of the 16 career clusters co-developed by national industry associations and state education leaders specify a mathematics competency threshold that includes advanced algebra and courses beyond.[3]

Wisconsin—along with other Midwest states—faces two major challenges: (a) developing career pathway programs which both create and retain a talented, high wage workforce that is able to meet the state's urban and rural infrastructure challenges, and (b) improving the mathematical competency of students across the K-16 educational pipeline. This research brief presents the results of an evaluation of Project Lead the Way, an innovative high school engineering program being increasingly implemented across the state. Evidence from the evaluation sheds light on how programs like this might help the state address these two challenges.

## The Challenge – Closing the Math Gap

Across the Midwest many high school students lack the analytic and math skills needed to succeed in today's high-skilled, rapidly changing workplace or to gain admission to college. Approximately two-thirds of Wisconsin's seniors complete the ACT each year, but in 2008 only *54% scored above the mathematics college readiness benchmark*—an ACT math sub-score of 22—indicating they could perform college algebra.[4] Two states (Michigan and Illinois) now require all high school students to complete the ACT as part of state high school assessment. By exposing all students to a college readiness assessment during grade 11, these states have moved to a more precise and useful benchmark. Students leaving high school receive essential information for accessing postsecondary education, as well as tips for what to study before re-taking the assessment. Equally important, education leaders and teacher learning communities receive student-level performance information to use in strategically improving instruction throughout high school.

*In 2008, 67% of Wisconsin seniors completed the ACT exam.*

**Percent of ACT Takers Meeting the Math College Readiness Benchmark Score of 22 (of 36 possible), 2008**

| In States Requiring All Students to Complete the ACT | | |
|---|---|---|
| Illinois | 40% | |
| Michigan | 31% | |
| **In Other Midwest States** | | **Percent of seniors completing the ACT, 2008** |
| Minnesota | 56% | 69% |
| Wisconsin | 54% | 67% |
| Indiana | 52% | 22% |
| Iowa | 50% | 60% |
| Ohio | 47% | 65% |

Source: 2008 ACT National and State Scores, http://www.act.org/news/data/08/dashboard.html

With the rapidly rising demand for and costs of postsecondary education, policymakers and parents are also increasingly focused on the issue of remediation. At the UW System campuses—including the two year and four year campuses--the percentage of new freshman requiring remediation in mathematics increased from 12.2% to 14.9% from Fall 2002 to Fall 2004.[5] During the same period, the percent of Wisconsin Technical College System students enrolling in basic skills courses grew by 18.0% to slightly more than 68,000 students, approximately 15.2% of the state wide WTCS enrollment.[6] With the Wisconsin graduation standards requiring only two years of math and two years of science credit, many seniors leave high school with limited and unclear prospects for gaining admission to four-year colleges, or face the challenge of doing remedial work at one of the technical colleges.

*Remediation rates continue to rise for first year college students in Wisconsin.*

**As the recent report of the National Mathematics Advisory Panel (2008) suggests:**

- Success in mathematics education is important for individual citizens, because it gives them college and career options, and it increases prospects for future income. A strong grounding in high school mathematics through Algebra II or higher correlates powerfully with access to college, graduation from college, and earnings in the top quartile of income from employment.
- The value of such preparation promises to be even greater in the future. The National Science Board indicates that the growth of jobs in the mathematics-intensive science and engineering workforce is outpacing overall job growth by 3:1 (p. xii).

Source: U.S. Department of Education. (2008). Final report of the National Mathematics Advisory Panel. Washington, D.C.: Author. Retrieved March 1, 2009 from: http://www.ed.gov/about/bdscomm/list/mathpanel/report/final-report.pdf

Of the fastest growing Wisconsin occupations for 2006-16, 80% require technical certificates or two year or four years postsecondary education degrees. Of the projected 8% growth in new or replacement positions through 2016, a career in science, technology, engineering and mathematics (STEM) sector make up 1 out of 5 new jobs.[7] For future members of the Wisconsin workforce, learning how design engineers use statistical and trigonometric functions to test safety restraints for cars, for example, is an opportunity to understand how theory is applied to real world problems. Equally important, by observing engineers they experience the real life demands of an engineering or technical career. As ACHIEVE, a national advocacy organization for the nation's governors and leading businesses, notes in its public awareness campaign—Career Readiness = Advanced Mathematics.

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## The Possibilities for Innovation

Efforts to focus high school learning on the STEM fields have been advancing rapidly across Wisconsin. With funding support from business and foundation partners, the State of Wisconsin, and federal legislation for career and technical education, 101 high schools and 50 middle schools implemented Project Lead the Way (PLTW) programs[8] during the 2008-09 academic year. Developed in upstate New York schools, nearly a decade ago, PLTW is an eight-course high school engineering curriculum using project and problem based learning strategies to acquaint students with the foundations (e.g., engineering design and principles) and selected specializations of engineering (e.g., biotechnical, aerospace, and civil and architectural). A fully implemented program provides students with 3-5 courses, along with four years of college preparatory math and science. End of course examinations for the engineering courses (similar to AP exams) provide college credit for high performing students. High school teachers with science, mathematics, and career and technical education backgrounds receive two weeks of intensive summer instruction from engineering professors to become certified instructors.

As high school leaders examine new curricula and instructional practices, close scrutiny is given to two recurring questions: To what extent are new curricula aligned with national and state content standards, and are students' learning and transition outcomes improved? Each of the PLTW core courses—Introduction to Engineering Design (IED), Principles of Engineering (POE), and Digital Electronics (DE)—includes instructional content that is aligned with both the high school mathematics standards of the National Council for Teachers of Mathematics (NCTM) and Midwest state standards. Moreover, in two courses—POE and DE-- students are exposed to key NCTM standards across more than half of the units. In these courses standards-based instruction is centered on plane and coordinate geometry, algebra, representation, connections, and problem-solving.[9]

*Two PLTW courses are math-intensive: Digital Electronics and Principles of Engineering.*

To address the college readiness question, the web-based content analysis tool developed by the Standards of Enacted Curriculum (SEConline.org) project was used to estimate the degree of alignment between the NCTM High School Standards and the ACT math assessment, with particular attention to the math standards emphasized in the POE and DE courses. This alignment analysis reveals that key mathematics content and process skills—which are included in the POE and DE courses—are assessed in the ACT Math examination, including the performance of procedures using: measurement, data functions, statistics and probability, algebra, geometry, and trigonometry, as well as completing analyses and proofs using measurement, geometry and data displays. Using the SEC content analysis tool, the coarse grain alignment index score was .416. This statistic is a score between 0-1 which measures the "consistency of main topics and expectations" between the NCTM standards and the standards assessed in the ACT math examination. This alignment index score suggests that the PLTW foundation courses have a modest chance of influencing ACT math scores.

Last year about 6,000 Wisconsin high school students (or two percent) completed one or more PLTW foundation courses. Locally, the range of implementation strategies is linked to the mission and organization of the high school. In high schools with a strong academic emphasis, PLTW courses are offered in the information technology or science departments, while in many comprehensive high schools these courses have helped to modernize the technology education programs which often serve a broad spectrum of students, including those most at-risk for not completing high school or entering college. Additionally, PLTW courses have been added to technical high schools, as well as used as the core curriculum for engineering-focused career academies or charter schools.

*Nearly 6,000 students enrolled in PLTW courses in 2008-09.*

Regardless of the local implementation design, the PLTW curriculum creates expanded learning and career development opportunities for students. Also, its implementation creates opportunities for in-school teacher collaboration on academic and technical course implementaion. Beyond the school it focuses workforce development discussions on how PLTW courses and specializations contribute to building a talented pool of gender and culturally diverse adult learners for the 21st century workforce.

## Integrating Engineering and Mathematics: Testing the Concept

Over the past three years CEW researchers have examined student engagement in eight PLTW high schools using surveys, focus groups, and locally collected data. In the most recent round of data collection, a promising pattern of findings regarding mathematics emerged at the TESLA Engineering Charter High School.

In 2001 school and community leaders opened a four-year Engineering Charter School at Appleton East, one of the city's three comprehensive high schools. After adding a grade to TESLA for each of its first four years, the school now serves more than 100 students annually from the city and surrounding school districts. The Appleton East Class of 2008 (n=347) included 27 seniors who had completed one or more PLTW engineering courses. In addition to completing foundation courses, approximately half of the seniors had completed advanced PLTW courses, including Digital Electronics, Computer Integrated Manufacturing, and the Engineering Design and Development course. The TESLA instructional team includes a mathematics instructor whose work with students both supplements and reinforces key mathematical concepts, statistical applications, and problem solving skills.

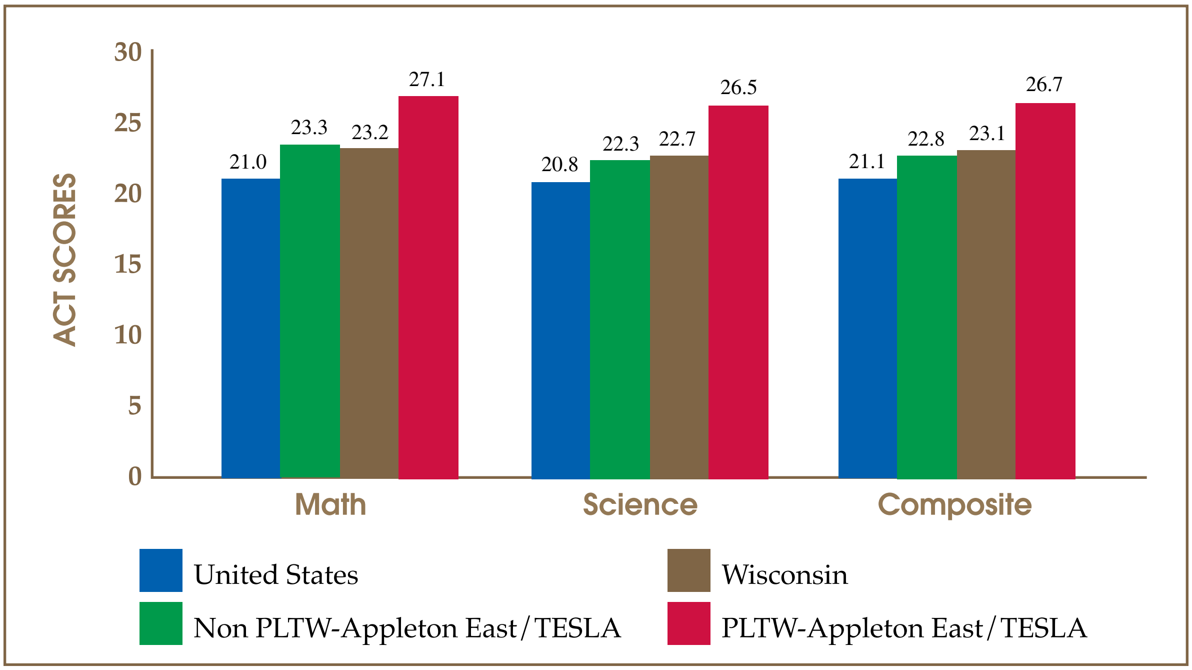
In Spring 2008, Appleton East High School was one of four Wisconsin high schools participating in a benchmarking case study to evaluate the effects of seniors' PLTW participation on academic outcomes, as well as levels of career and college readiness. The nationally prominent High School Survey of Student Engagement (HSSSE) was administered to members of the senior class in April and May. Subsequently, school district data analysts linked the HSSSE results to each student's academic and course taking record using the student's state ID number. Researchers were provided with a de-identified set of data from each high school for analysis. To gather information about the students' and faculty perceptions of the PLTW courses and the TESLA small school culture, focus groups were conducted with seniors and with several instructors, counselors and administrators. *(A companion research brief, entitled Value Added Engineering Education, describes the academic outcomes and student engagement findings from the other high schools and three middle schools.)*

### At TESLA, our case study revealed the following major results:

*At one high school, PLTW courses are linked to significanly higher ACT scores.*

1. After controlling for the influence of gender, family income, and students' prior academic performance on the 10th grade state assessment, the PLTW seniors were significantly more likely to achieve both a higher ACT composite score ($p<.05$) and a higher ACT mathematics score ($p<.05$). When compared to the average ACT scores for Appleton East seniors (23.1), the TESLA graduates' average composite ACT score was 26.7—a score that is above the admission requirement for engineering majors at selective admission universities.
2. On measures of college readiness, the PLTW seniors reported significantly higher levels of intellectual openness, such as discussing open ended questions and being motivated by a desire to learn.
3. The PLTW seniors are more proactively pursuing career exploration activities ($p<.05$) than their peers, including talking with adults about career goals and participating in school experiences that help them clearly define career goals.
4. Comments from TESLA seniors indicated that PLTW courses had provided several benefits, including but not limited to: (a) using advanced mathematics skills in planning and completing their capstone engineering design project, (b) being able to make sense of prior school learning through the engineering courses, and (c) interacting with a group of local engineers about their projects and presentations.

Figure 1. ACT Scores for the Class of 2008




### Conclusions

The case of Appleton East/TESLA provides a proof-of-concept that mathematics achievement can be raised through engineering and technology education programs. It is important to note that these results do not *definitively* answer the causal question of whether observed differences between students who did and did not participate in PLTW can be attributed to the program. Students were neither randomly assigned to PLTW nor to the engineering charter school, and statistical controls for student background may not have fully accounted for differences between the two groups. However, this finding that a full and rigorous implementation of PLTW and academic courses was positively and significantly associated higher college admission test scores, especially scores that are required for admission to leading engineering colleges and universities, should stimulate and guide further efforts to discover new approaches that better prepare all students to pursue postsecondary education and careers in STEM fields. The findings emerging from this analysis, which compared the experiences of PLTW and non-PLTW high school seniors, suggests several next steps for local school, business, and community leaders:

*Teacher profesional development is essentioal to integrating and maximizing accademic and technical learning.*

1. As high schools implement PLTW and other integrated technical-academic curricula, it is imperative to explicitly align and strategically reinforce the math, science and English competencies that are embedded in the engineering curriculum. As demonstrated at TESLA, algebra and geometry instructors can help students see how precise measurement and product failure probability estimates are essential skills for engineers who are designing cell phones or iPods. Other studies have documented the feasibility of teaching the mathematics embedded in technical subjects to raise scores on math assessments while not jeopardizing or reducing technical competencies.[10] At TESLA, the significantly higher ACT scores (~27) were achieved by PLTW seniors who had completed about the same number of math and science credits (~3.3 credits) as non-PLTW seniors. Team-based, school-focused teacher professional development efforts are an essential ingredient for raising the level of academic outcomes generated from PLTW instruction, as well as other college and career readiness initiatives seeking to improve academic and technical learning.

2. High school leaders need to compile and analyze longitudinal data on their graduates and link it to the student record data in district offices. By analyzing students' transitions through high school and on to postsecondary education, strategic instructional improvements can be identified for beefing up the physics or trigonometry content that college freshman find to be challenging. It is especially important to disaggregate these data sets to understand how females and students from low income families are experiencing the transition into collegiate STEM programs.

In summary, the National Academy of Science has characterized the increasingly "higher stakes" associated with integrating engineering, mathematics and science at the high school level:

> If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for a new wave of change. While there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today. (The Engineer of 2020: Visions of Engineering in the New Century, 2005, p. 5).

The systematic implementation of PLTW courses and programs by high school faculty teams is the central resource for preparing the next generation of engineers, technicians, and technology-literate citizens. It is abundantly clear—from this point forward each generation must create solutions to a litany of emerging societal challenges, such as restoring the urban infrastructure, as well as discovering solutions to challenges that are yet to be uncovered.

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## Notes

[1] National Academy of Engineering. (2009). Grand engineering challenges. Washington, D.C. : The National Academies. Retrieved March 2, 2009 at: http://www.engineeringchallenges.org/cms/8996/9136.aspx

[2] Office of Economic Advisors, Department of Workforce Development. (2008). STEM occupations in Wisconsin: Outlook and impact. Madison: State of Wisconsin.

[3] Based on an analysis of the high school mathematics requirements in the programs of study for the 16 states' career clusters. See example program of study at http://www.careerclusters.org/resources/pos_ks/FoundationPOS/ARTS-Cluster-POS.pdf

[4] ACT High School Profile Report, Graduating Class of 2008—Wisconsin. Retrieved March 2, 2009 at: http://www.act.org/news/data/08/pdf/states/Wisconsin.pdf

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[7] Office of Economic Advisors, Department of Workforce Development. (2008). STEM occupations in Wisconsin: Outlook and impact. Madison: State of Wisconsin.

[8] Details on the Project Lead the Way Engineering Program can be found at: http://www.pltw.org/

[9] Nathan, M., Tran, N., Phelps, L.A. & Prevost, A. (in press). The structure of high school academic and pre-engineering curricula.

[10] Stone, J.R., Alfeld, C., Pearson, D, & Lewis, M.V. (2006). Building academic skills in context: Testing the value of enhanced math learning in CTE. Minneapolis, MN: National Research Center for Career and Technical Education, University of Minnesota. Retrieved March 10, 2009 at http://cehd.umn.edu/NRCCTE/BldgAcadSkillsFinal.html