OPENING ACCESS TO STEM CAREERS

Robert Goodman, Ed.D.

Introduction

There is a well-recognized need for the United States to prepare more of its citizens to participate in STEM-related careers. However, structural problems within our educational system have proven to be significant obstacles. The impact of those obstacles is greater on underrepresented minorities and the economically disadvantaged, so they have a negative impact on both our economic competitiveness and social justice.

The New Jersey Center for Teaching and Learning (CTL), through its use of the Progressive Science Initiative® (PSI®) and the Progressive Mathematics Initiative® (PMI®) has overcome some of those obstacles by solving an interlocking set of problems in middle/high school science education. Scaling up those solutions will prepare more high school graduates for STEM majors and careers, but it will take time for those solutions to spread to enough schools. To address more students, more quickly, these solutions need to be applied in higher education as well. CTL's middle/high school solutions hold promise for higher education because the same structural barriers face college learners.

To make up for current deficiencies in the U.S. system we need a number of "on-ramps" to STEM careers located at critical points throughout P-20. While the ideal solution would keep all children engaged in STEM learning from kindergarten forward, we cannot afford to wait for current preschoolers to fill the STEM jobs that are open now, nor can we count on all students staying on one continuous path from Pre-K through high school graduation. We need to act with urgency across all grade levels.

One proposal contained in this document is for higher education to offer two physics courses that have proven to be a welcoming pathway to science and mathematics for the many students who have insufficient backgrounds in those subjects. These courses include a first semester algebra-based physics course and a second semester trigonometry-based physics course.

A second proposal is to establish a dual-enrollment process to provide college credit for these courses, regardless of when and where they are taken. This will encourage more students to take science and mathematics in high school so that they enter higher education better prepared.

A third proposal is that higher educational institutions partner with CTL to develop teacher preparation programs. These programs will dramatically boost the number of high school physics and chemistry teachers, so that all students have access to those subjects.

The combination of these three proposals will dramatically increase the number of students, of all ages, who have access to STEM career pathways.

P-20 Overview: the Evolution of Interlocking Solutions

Almost all STEM majors in college or university require students to study physics, chemistry and calculus. Students who have studied those subjects in high school have a distinct advantage. The problem is that too few students enter higher education with a strong P-12 STEM background, and those least likely to have that background are students who are Black/Hispanic and/or economically disadvantaged. For instance, fewer than half of New York City high schools offer physics, and only about 20% of NYC students graduate having studied physics. Thus, at least 80% of NYC high school graduates are unprepared to study subjects required for a STEM-related major (Issues of Equity in Physics Access and Enrollment - http://njc.tl/wi, and The Crisis in Physics Education - http://njc.tl/wx)

There are two possible solutions to this problem:

- All students study physics, chemistry and advanced mathematics in high school.
- Higher education provides a welcoming pathway to STEM majors for students who did not learn those subjects in high school.

The prospects for requiring all high school students to study physics, chemistry, and advanced mathematics are limited by the severe shortage of physics and chemistry teachers. While CTL and others are working to address that problem, it is unlikely that significant change will occur at scale unless higher education changes its approach to the STEM pipeline and STEM teacher preparation, including providing additional on-ramps to STEM at the college level.

A journey that began in September 1999 with the goal of improving science education for 16 pre-engineering students at a New Jersey vocational/technical high school has carved a path that can open the way to the U.S. becoming the global leader in science and mathematics education.

The challenge in 1999 was to launch a new high school pre-engineering program with 16 students who had inadequate middle school preparation for this technical major. Despite being accepted into this program with the understanding that they had completed Algebra I, only three of the sixteen had actually completed that course. This need to bring underprepared students up to a very high standard in science and mathematics education is mirrored across P-12 and higher education. Therefore, it is not a coincidence that the solution that worked for the initial 16 students proved helpful as a model for P-12, and can prove the same for higher education.

Presuming that these students were proficient in Algebra I, they were scheduled to take geometry and biology (biology was then the 9th grade science in the school). Outside of the standard academic schedule, the pre-engineering program had two hours each day with its students.

Because of our enrollees' limited algebra and physics skills, we chose to augment 40 minutes of engineering study with 40 minutes of algebra, and 40 minutes of algebra-based physics.

The unique physics course we designed has a pivotal role in this story. It was designed:

- To be mathematically rigorous, using only algebra so that all the students could succeed in it.
- To provide motivation for the learning of algebra by showing its usefulness to students.
- To be the foundation for a logical flow of science from physics to chemistry and then on to molecular biology.
- To lead to AP science exams so that program graduates would have external validation of what they learned and in order to increase the likelihood that students from a new vocational high school would be accepted to high quality colleges/universities.
- To use pedagogy that would be a welcoming introduction to science and math to all students, since most of the program participants lacked prior success in traditional mathematics and science classes.

This physics course, which would become PSI Algebra-Based Physics, needed to be welcoming to all students while providing access to highly rigorous mathematics and science. To accomplish that we first sliced the AP Physics B curriculum in a way that was not traditional: rather than splitting the content into two years by topic, we divided it by the level of mathematics. Since more than 80% of AP Physics B just requires algebra, and since most 8^{th} and 9^{th} grade students are working to master algebra, we did not use trigonometry in the first year physics course. Some courses that purport to be algebra-based include trigonometry, adding an insupportable cognitive load onto students who are just internalizing their understanding of algebra.

The next step was to choose topics based on their value in preparing students for chemistry and biology, to provide a coherent progression of learning. These include mechanics; electricity & magnetism, simple harmonic motion and waves; and quantum & nuclear physics. In that way, the course prepares students for chemistry and biology courses over the next two years, as well as the elective PSI Trigonometry-based Physics (AP Physics B). By the end of that second physics course, students have mastered exactly the same AP Physic B content that they would have if they had been required to use trigonometry in both physics courses, but by reserving the use of trigonometry to the advanced elective course, the path has been opened to all students.

The pedagogical blend we developed was as unique as the course content. It intertwined direct instruction with social constructivism. The design was geared to succeed with a wide range of students who could support one another as they sat at round tables solving problems and discussing mathematics and science. The details of how this was accomplished are explained in Squaring the Circle (http:/njc.tl/wc) and PSI-PMI: A New Educational Paradigm (http://njc.tl/we), as well as my doctoral dissertation (http://njc.tl/wd).

The positive results of this new approach to content and pedagogy were striking. The piloting school created the opportunity for students in other vocational majors to take not only our physics course but the complementary chemistry and biology courses as well. Eventually, the pre-engineering science program became the science program for all students, including general and special education students. By 2012, this very school became #1 in New Jersey for the percentage of students taking and passing AP Physics B.

These results were a key reason for my being named the 2006 New Jersey State Teacher of the Year. I completed my doctoral dissertation based on PSI: how it worked and its results. Five factors came together between 2006 and 2009, leading to this work being scaled up:

- The New Jersey Department of Education (NJ DOE) had a strong interest in seeing if what was done in the pilot school could be extended to other NJ schools.
- The conclusion of my dissertation included the recommendation that it would be important to see if the results in the pilot school could be replicated in other schools.
- As a reward for becoming State Teacher of the Year, I was given an interactive whiteboard and student polling devices.
- The New Jersey Education Association (NJEA) formed the New Jersey Center for Teaching and Learning (CTL), a nonprofit organization with the mission of empowering teachers to lead school improvement, and asked me to join its board.
- A new law was adopted authorizing alternative methods of certifying new physics and chemistry teachers.

All these elements worked together to increase the number of New Jersey schools adopting PSI. Early replication efforts revealed two large obstacles. First, all course materials had been created in the pilot school, which had stopped using physics textbooks since none existed offering mathematical rigor limited only to algebra in the first year course. Second, the most likely early adopters were urban schools open to change because of a clear need to improve in math and science instruction. While being the most open to change, those schools had few, if any, physics teachers.

We faced two intertwined questions here: Could the PSI program be replicated in other schools? Could teachers learn and then teach physics effectively without a traditional physics background? In theory, it would have been best to separate these two experiments; in practice, that was not possible. Both had to be done at once since we needed the teachers to learn the content and teach it at the same moment the PSI Algebra-Based Physics course was launched for students in their schools.

We solved the first problem by using the interactive whiteboard and student responders I won for my classroom. This technology enabled us to capture PSI's content and pedagogy so that teachers in other schools could use those same resources.

We solved the second problem by working with the NJ DOE to develop a summer program to enroll current teachers of any subject in physics, and teach them the same way we taught students. Since we had shown that all students can learn physics, why not all teachers? The first group of teachers began in the summer of 2009. After 114 hours of summer instruction, these teachers used the same materials and methods with which they had learned physics to begin teaching PSI Algebra-Based Physics to their own students in the fall. While teaching students PSI Algebra-Based Physics, they met for another 200 hours, one night a week and every third Saturday, to learn the content, and how to teach the content, of Trigonometry-Based Physics (AP Physics B).

The results provided strong support that PSI can be replicated in other schools and that its approach to training teachers strengthens student achievement. Here are some points of note:

- CTL has been the #1 producer of U.S. physics teachers for each of the five years since its teacher training program launched and has produced nearly 100 new physics teachers and 30 new chemistry teachers in that period. That is nearly double the number graduated by the top university producer of physics teachers.
- Six of the top 12 schools in NJ for AP Physics B participation are schools in which PSI is used. In PSI schools, more than 60% of the students are Black/Hispanic and are economically disadvantaged, as compared to less than 8% in the non-PSI schools in the top 12. (Ninth Grade Physics Reverses Science Achievement Gap - http://njc.tl/wf)
- In Newark, the state approved Algebra I test was given to all students taking Algebra I: the 300 students enrolled in PSI Algebra-Based Physics scored 14% higher than those in an environmental science course. (Newark Students Demonstrate Dramatic Gains in Algebra Scores - http://njc.tl/wg)

Aside from the continued expansion of CTL's work in New Jersey schools, the work of PSI is expanding into four other areas:

- The Progressive Mathematics Initiative® (PMI®) K-12 mathematics courses have been launched based on PSI, the Common Core State Standards and College Board Calculus standards.
- CTL is working on the ground to replicate PSI-PMI in Colorado, a state in Argentina, and The Gambia (West Africa; supported by the World Bank and Peace Corps.)
- PSI K-8 science courses have been launched based on the Next Generation Science Standards.
- A website, www.njctl.org, which hosts all PSI and PMI course materials, has undergone exponential growth as students and teachers around the world use these courses. In the last 12 months, the site has had 3.4 million pageviews by more than 175,000 unique visitors, and the current pace is double that. Over 6,100 teachers have registered to gain access to student assessment materials.

A Higher Education Proposal

PSI was designed to solve the problem of raising inadequately prepared high school freshman to the level of being successful in a demanding pre-engineering major. Eventually, it proved capable of eliminating tracking and elevating all students to that high level. PSI has demonstrated that students can learn and enjoy science and mathematics. This was accomplished by correcting the high school science sequence to physics-chemistry-biology, aligning mathematics and science courses so that they complement each other, and using effective new approaches to teaching and learning.

The long-term goal of CTL's work in K-12 is to have all students enter higher education prepared for the college-level science and mathematics courses needed for STEM majors. Today, because most U.S. high school students do not take physics or chemistry and often, when they do, those courses are not taught effectively, most U.S. college freshmen know little more physics or chemistry than high school freshmen.

Further, it's clear from Accuplacer entrance exams that many high school graduates are still not fluent in algebra, let alone trigonometry. Most state exit examinations for high school graduation remain at an 8th grade math level; they do not require an understanding of algebra.

In the past, enough students entered higher education with a sufficiently strong background in math and science to succeed in the traditional college/university course sequence. There were enough students ready to move forward into STEM careers, and there were enough other career options for those who had little STEM preparation. This is no longer the case; we cannot afford to give up on students who did not receive a sufficient P-12 education to be ready for traditional higher education science and mathematics courses. In addition to failing to provide a sufficiently robust 21st century workforce, giving up on underprepared students disproportionately impacts students who are female, members of underrepresented minorities, and/or the impoverished, which perpetuates social and economic inequities.

The first part of our proposal is that higher education offer two new one-semester physics courses, the first semester to be purely algebra-based and the second semester trigonometry-based. In the second course, first semester topics will be deepened using trigonometry and expanded upon by adding trigonometry-based topics. At the end of the second semester, students will have mastered the same content as if they had taken the two traditional trigonometry-based physics courses, but PSI's approach will make that learning more accessible to a more diverse group of students.

The second part of our proposal is to create a system to provide college credits to middle and high school students who demonstrate mastery of the content of either or both of these courses. This will save successful students time and money and provide an incentive to middle and high school students to take those courses, providing better prepared students to colleges and universities.

The third part of our proposal relates to teacher preparation. The U.S. will need about 35,000 new physics and 20,000 new chemistry teachers if all students are to study those subjects. Currently, higher education is only producing a few hundred physics teachers a year - barely enough to account for teacher retirements - not enough to create any net new physics teachers. The fact that the 25 physics teachers created each year by CTL represents nearly 10% the output of all of higher education combined shows both the scope of the problem and its potential solution (CTL – The #1 Producer of Physics Teachers - http://njc.tl/wh). By using PSI's approach to teaching both physics and chemistry content, and how to teach those subjects effectively, schools of education will be able to scale up CTL's work, creating the large numbers of new physics and chemistry teachers that are so urgently needed.

Taken together, these three proposals hold the promise of preparing more U.S. citizens to participate in STEM-related careers, dramatically improving the prospects for our county by improving our economic competitiveness and addressing a key issue of social justice.