Education Commission of the States

No Time to Waste: The Vital Role of College and University Leaders in Improving Science and Mathematics Education

Presented at the Invitational Conference on

Teacher Preparation and Institutions of Higher Education: Mathematics and Science Content Knowledge

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No Time to Waste:
The Vital Role of College and University Leaders in Improving Science and Mathematics Education

Overview

Not since the Soviet Union's launch of the Sputnik satellite – 47 years ago this week – has the need to improve science and mathematics education in America been as clear and as urgent as it is today. And never has it been more apparent that the pivot point for change and improvement is the nation's teachers and the institutions that train them.

America's competitive edge in the global economy, the strength and versatility of its labor force, its capacity to nourish research and innovation – all are increasingly dependent on an education system capable of producing a steady supply of young people well prepared in science and mathematics.

But all along the pipeline – from the quality of science and mathematics instruction in the early grades, to the performance of our high school seniors on international tests, to the content and rigor of teacher-education programs in our colleges and universities – there are troubling weaknesses, gaps and disconnects.

The complexity, dimensions and already-emerging consequences of the problem were made clear in a report issued last spring by the National Science Board.

Over the past two decades, the report noted, the U.S. science, engineering and technology workforce has grown at more than four times the rate of total employment, in large part because of our ability to integrate large numbers of foreign-born scientists and engineers into the workforce. But in the global marketplace, competition for these workers is steadily widening and intensifying.

At the same time, the proportion of U.S. citizens qualified to fill science and engineering jobs is stagnating. The number of young people preparing for careers in these fields has steeply declined, and a large portion of the current workforce is rapidly approaching retirement age. Complicating matters, America's college-age population will increasingly be made up of Hispanics and blacks, whose participation rates in science, engineering and technology are half or less those of white students.

In the face of these potent and converging trends, efforts to reform and strengthen mathematics and science education have been largely piecemeal and unfocused, and yielded only modest gains. In the past few years, the report noted, classroom access to computers and the Internet has expanded significantly, as has the availability of Advanced Placement science and mathematics courses. Nearly all states have established academic standards in both science and mathematics, and the annual testing of students in core subjects mandated by the No Child Left Behind Act will be extended, in the 2007-08 school year, to include science.

Still, on a number of key indicators, America's system of science and mathematics education continues to perform below par.

This paper focuses on what is increasingly seen as the major stumbling block to fundamental and lasting change – the quantity, quality and classroom practices of science and mathematics teachers – and on what higher-education leaders can and must do address it.

Five years ago, I had the privilege of chairing a task force created by the American Council on Education to study reforming teacher education. The task force's report, *To Touch the Future: Transforming the Way Teachers Are Taught*, urged college and university presidents to take the lead in upgrading and elevating the importance of teacher-preparation programs.

In the course of its work, the task force found that pre-service programs typically suffer from a lack of regular evaluation, a flabby curriculum, and low entrance and exit requirements. Far too many fail to adequately provide their graduates with what they need to persevere and succeed: a good grounding in subject matter as well as teaching methods, a solid introduction to classroom technology, and support and mentoring -- especially important for those who teach in high-poverty schools and special-needs programs.

To Touch the Future called on presidents and other higher education leaders to move the improvement of teacher-preparation programs to the top of their institutions' agendas. They should insist that the whole of the university, and especially the arts and sciences faculty, take responsibility for preparing teachers. And they should speak out on public issues linked to teaching quality, ranging from teacher pay to federal funding for education research.

Those and other elements of the 10-point action agenda laid out in the task force's report form the basis of the recommendations with which this paper concludes. That agenda is, in my view, every bit as sound and sensible today as it was five years ago, and I urge all of you to give serious and immediate consideration to what you can do, both individually and collectively, to move it forward.

But first, let's take a closer look at the general condition of science and mathematics education from two perspectives: student achievement and teaching quality.

K-12 Science and Mathematics Education: A Status Report

Too many elementary and middle school students aren't being equipped to achieve in science and mathematics. In the most recent of the Philadelphia-based Bayer Corporation's annual reports on science education in the United States, only one-third of elementary teachers reported teaching science every day, and one in three said they teach science only twice a week or less. As for mathematics, one in three 8^{th} graders in the United States attend schools that do not offer them an algebra class – widely considered a "gatekeeper" course for the more advanced science and mathematics courses.

A significant proportion of elementary school teachers lack confidence in their ability to teach science. The Bayer report, which surveyed both elementary teachers and deans of schools of education, concluded that K-5 science education needs considerably stronger emphasis at the pre-service college/university training level. Among the major findings:

- When asked to rate the quality of science education in their schools, only 18% of the teachers surveyed assigned it an A, and nearly one-third assigned it a C or D. Only 7% of the deans surveyed said they were "very confident" that elementary school pupils are receiving a good science education. More than half, 56%, said they were "a little confident" or "not confident" at all.

- Only 14% of the teachers surveyed gave an A rating to their pre-service training in science. And a strikingly large percentage – 35% – said they rely more on what they learned in their high school science courses than on what they learned in college to teach science.

- Two-thirds of the teachers surveyed named science as the subject they wish had been given more emphasis during their pre-service training. A large majority of both deans (84%) and teachers (72%) agreed that "elementary teacher education programs should require their undergraduates to take more coursework both in science itself and in science teaching methods."

- Only one in 10 teachers said they have participated in programs that give teachers the opportunity to work directly with scientists and/or engineers on science curricula and other professional development activities. Among those who had, an overwhelming majority said the experience had helped them better understand science content, improved their teaching of science content, and bolstered their motivation and enthusiasm for teaching the subject.

Troublingly large numbers of the nation's middle school and high school students receive science and mathematics instruction from underqualified teachers.
According to the National Science Board's recently released *Science and Engineering Indicators 2004:*

- Eighteen percent of high school students – and 57% of middle school students – studied mathematics with a teacher who did not major or minor in mathematics or a related field.
- Fifteen percent of high school students – and 34% of middle school students – received instruction in biology/life sciences from a teacher without a degree in biology, life sciences or a related field.
- Sixteen percent of high school students – and 48% of middle school students – received instruction in physical sciences from a teacher without a major or minor in a physical science, engineering or a related field.
- High-poverty and high-minority schools both had a higher proportion of inexperienced and/or underqualified science teachers than low-poverty and low-minority schools.

Despite some overall gains in achievement, most American students still perform below levels considered proficient or advanced on national science and mathematics assessments, and there are large and persistent gaps in achievement between various ethnic/racial subgroups. On the 2000 National Assessment of Educational Progress (NAEP) science and mathematics tests:

- Just one-fourth of 4^{th} and 8^{th} graders – and only 17% of 12^{th} graders – scored at or above the proficient level in mathematics.
- In science, roughly one-third of 4^{th} and 8^{th} graders – and nearly half of 12^{th} graders – did not reach even the basic level of competence.
- In both subjects, at all grade levels, very few students (2-5%) performed at the advanced level.
- At all three grade levels, in both mathematics and science, significantly higher proportions of white and Asian/Pacific Islander students scored at or above the basic and proficient levels compared with black, Hispanic and American Indian/Alaskan Native students. As an example, only one in 10 Hispanic 8^{th} graders scored proficient or advanced in mathematics (compared with roughly 40% of whites and Asian/Pacific Islanders), and 60% scored below the basic level (compared with just 22% of whites and Asian/Pacific Islanders).

In international comparisons, U.S. student performance in science and mathematics is at best only slightly above average, and becomes weaker and weaker as students progress through school. On the Third International Mathematics and Science Study (TIMSS), which tested nearly a half-million students from 41 countries, U.S. 9-year-olds scored somewhat above the international average; 13-year-olds, near the average; and 17-year-olds, below it. What's more, even U.S. students taking advanced mathematics and science courses did not fare well in comparison with their international counterparts. On an advanced science assessment administered by TIMMS, U.S. students who were taking or had taken physics I and II, advanced physics or Advanced Placement physics were outperformed by students in all but one of the 15 other countries participating in the test.

At a time when the number of jobs to be filled in engineering and science is predicted to continue growing at more than three times the rate of other professions, fewer and fewer high school students are interested in – and prepared for – obtaining a college degree in those fields. According to the National Science Board's 2004 report:

- In 1975, the United States ranked third in the world in the percentage of students pursuing natural science and engineering degrees. Now it is 17^{th}.

- Over the past 10 years, the number of high school seniors planning on careers in engineering has dropped more than 35%.

There are other troubling signs. While most potential engineering students have taken high-level math and science in high school, one recent study found that the number of those students graduating in the top quarter of their high school class has decreased from 63% to 55% since

1991. Twenty-four percent of those students reported needing additional help in math, and nearly half percent said they need help in study skills to prepare for a rigorous engineering curriculum. Remedial coursetaking is widespread, particularly at two-year colleges, where enrollment in remedial classes accounts for 55% of mathematics enrollment.

The Teaching of Science and Mathematics: What the Research Shows

***Teachers* Matter**

No factor is as important to improving student achievement as a good teacher. A growing body of evidence points to the crucial relationship between teaching quality and student learning. For example:

- A study of student performance in Texas found that the teacher's ability was the single most influential determinant, outside of home and family circumstances, of student success (Ferguson, 1991).
- A study in Tennessee found that students who had good teachers three years in a row showed a significant increase in their percentile rankings on state examinations – regardless of socioeconomic factors. On the other hand, students who began at exactly the same percentile and had a series of ineffective teachers during that same period showed a significant decrease in rankings (Sanders and Rivers, 1996).
- A 1996 study found that increased funding for teacher education had a greater effect on increasing student achievement than did teacher experience, increasing salaries or lowering class size (Greenwald, 1996).

What Teachers Know Matters

While research until now has been only moderately supportive of the relationship of teacher content knowledge to student achievement (Allen, 2003), it is clear that what a teacher does not know, he or she cannot teach.

A 1999 study of mathematics instruction at the elementary school level found a strong link between the depth of classroom lessons and the depth of teachers' own knowledge of the subject. "Not a single teacher was observed who would promote learning beyond his or her own mathematical knowledge," the study stated, and went on to conclude: "A teacher's subject matter knowledge may not automatically produce promising teaching methods or new teaching conceptions. But without solid support from subject matter knowledge, promising methods or new teaching conceptions cannot be successfully realized." (Ma, 1999)

How Teachers Use What They Know Matters

Recent research has shed light on the importance of teachers' depth of content knowledge and their ability to communicate it in various forms.

One recent study of mathematics teaching, for instance, concluded that (1) teachers need a particular type of content knowledge that allows them to guide different learners to the same learning and (2) this type of "flexible and expressible" content knowledge is positively linked with student learning (Hill et al, 2004). Teachers with this sort of knowledge, the study found:

- Are able to "unpack" ideas and procedures to make their reasons available to students.
- Can "positively and substantially" affect the learning of mathematics, particularly in low-performing/high poverty schools.
- Are needed not only at the higher grade levels, but in the early grades, where "teachers' mathematical knowledge for teaching predicts student gains." (For more details on this specialized knowledge and skill set, refer to Appendix B.)

The research, then, is clear: teachers cannot teach what they do not know and they cannot teach what they know if they do not have the skills to do so. Changing *teaching* is the single most powerful way to improve science and mathematics competency in the United States – and the responsibility for doing so rests squarely on the shoulders of the institutions that educate and train them.

What College and University Leaders Can and Must Do

Step forward as visible, vocal advocates for improving science and mathematics education at all levels.

Every citizen in the nation has a stake in the effectiveness of the nation's schools. College and university presidents have a special responsibility and opportunity to build alliances with external constituencies and to develop stronger public support for learning at every level by every sector of society.

Presidents need to be visibly engaged, vocal advocates for the improvement of science and mathematics education, in particular. They need to forge and strengthen ties with the K-12 school system, with state departments of education, with legislators and other policymakers, and with business leaders. They can make their presence felt at public events, write opinion pieces of newspapers, and appear on broadcast talk and news programs.

College and university presidents enjoy the confidence of the public and have a visible platform from which to speak. On the issues of teacher education, high-quality schools and role of learning in our society, presidents need to be heard.

Take the leading in moving the education of teachers to the center of the institutional agenda.

Teacher education can no longer be allowed to stand as a marginal program, and ought not to be treated with benign neglect. Presidents and chief academic officers must initiate efforts to re-examine and clarify the strategic connection of teacher education to the mission of their institutions. Learning in the discipline and clinical practice must be brought together into a cohesive whole; such integration must occur at the campus level, and be driven by the sense of urgency and necessity that presidential leadership commands.

Similarly, the policies that underpin teacher-education programs – such as admission standards, curricular decisions and graduation requirements – need to be set at the institutional level. If policy is to change, and if issues and problems are to be confronted, leadership must emerge at the senior administrative level.

Initiate a comprehensive review of the quality of their institution's teacher-education programs focused on:

- The extent to which prospective teachers receive a solid grounding in (1) the academic content area in which they expect to teach, (2) pedagogical principles and proven practical skills and (3) the impact and application of technology as a pedagogical tool in the classroom.
- The quality of students admitted to the program. Admission standards, retention practices and the academic performance of students in teacher-education programs should match or exceed those of the student body as a whole.
- The steps that teacher-education programs are taking to attract and retain talented minority students.
- The adequacy of institutional tracking mechanisms to measure and monitor the performance of teacher-education graduates – and, therefore, the quality and performance of the program itself.

In addition, every institution of higher education that offers an academic program of teacher education should secure some periodic, reliable form of third-party assessment, either through accreditation or through the appointment of an independent visiting committee.

Make it clear that that the responsibility for preparing teachers rests not just with the school of education, but with the institution as a whole – especially the arts and sciences faculty.

Presidents, working through their chief academic officers, should give strong and visible support to the appointment of an oversight committee of academic leaders – from both the arts and sciences and education – to redesign and supervise teacher-education programs. The goal should be to bring disciplinary, pedagogical and clinical expertise together into a unified whole.

Particular attention should be paid to ensuring that teachers fully understand state and national science and mathematics standards, and are capable of bringing them to life in the classroom.

Establish more functional relationships and clearer pathways for recruitment and transfer among institutions.

Most of today's college students – including prospective teachers – attend more than one institution before receiving a degree. Carefully crafted articulation agreements can strengthen the quality of academic programs, enable students to move smoothly from one academic setting to another and, ultimately, improve the quality of teachers available to serve the nation's schools.

Articulation agreements with community colleges hold special promise for improving the diversity of the teaching force. Community colleges enroll a larger proportion of minority students than four-year institutions, and they are also an entry point for many mid-career adults. Establishing functional relationships with other colleges and developing clearer pathways to degree completion are two good ways of expanding the number of students pursuing careers as teachers.

Ensure that graduates of their education programs are supported, mentored and tracked over time.

Teachers' career development and persistence, as with other professionals, depends on continuous learning and support. Clinical partnerships between higher-education institutions and K-12 schools to provide new teachers with ongoing assistance and mentoring would significantly enhance the chances of their success and survival.

Just as important, colleges and universities, working in partnership with the schools, should assist experienced teachers with strong, well-crafted professional development opportunities that utilize both the faculty and the research resources of the institution. In addition to strengthening teachers' skills in managing the changing classroom and keeping current in subject matter knowledge, such programs provide peer support for teachers and maintain an essential link between institutions of higher education and K-12 schools.

Newly minted and experienced teachers alike can benefit from programs that give them the opportunity to work directly with scientists and/or engineers on curriculum design and other professional development activities. Such experiences can deepen their understanding of content, sharpen and strengthen their teaching skills, and bolster their motivation and enthusiasm.

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Appendix A:
On the Leading Edge

Here are three outstanding examples of innovation and leadership in mathematics and science education on the part of institutions of higher education.

Purdue University's Department of Engineering Education

Purdue University's top-ranked College of Engineering has created a one-of-a-kind program aimed at both increasing and diversifying the pool of high school students who are interested in –- and well prepared for -- a career in the field of engineering.

A new Department of Engineering Education, approved by the university's board of trustees in April 2004, will initially focus on research and outreach, and over the next several years expand to include undergraduate and graduate degree programs operated in conjunction with Purdue's School of Education.

Outreach. The new department's outreach efforts will focus primarily on professional development for educators and bringing engineering into K-12 schools. Following models used in other disciplines, the department and its faculty will work with classroom teachers to develop curricula to introduce younger students to the higher-level thinking common in the problem-solving and design principles of engineering.

Existing programs that put Purdue engineering students in K-12 classrooms will also be expanded. This will not only allow younger students to understand engineering, but it also expose girls and minority students to role models in the field, increasing the likelihood they will consider an engineering career.

Research. The new department's faculty will focus research on the science of learning, the role of technology in education, assessment of student learning, diversity and learning environments, and other topics leading to the improvement of engineering education. A major emphasis will be on understanding how best to teach engineering concepts to a wider variety of students, beginning at a younger age.

Undergraduate and graduate degree programs. A program for educating certified high school teachers with an emphasis in engineering is expected to be in place by 2006. Besides teaching high school engineering courses, teachers would be qualified to teach mathematics, physics and other sciences and have the knowledge to bring engineering concepts into the classroom. Undergraduate students working toward teacher certification would work closely with Purdue's School of Education, taking some of the schools' teacher preparation courses.

Plans also call for the development of accredited undergraduate degree programs in engineering education and interdisciplinary engineering, and graduate degree programs for students studying the science of learning and other topics in engineering education.

University of Texas at Austin's UTeach Program

The UTeach Program is a joint effort of the University of Texas at Austin and the Austin Independent School District to recruit, prepare and support the next generation of math and science teachers for the state of Texas. This collaborative approach to teacher preparation has shown exceptional promise in attracting new students to math and science education. UTeach combines practical experience and scholarly investigation with early and ongoing field experiences aimed at capturing the imagination of pre-service teachers and providing a foundation for more advanced pedagogical courses.

UTeach was created in 1997 under the leadership of the deans of the university's College of Natural Sciences and College of Education. The faculty of the two colleges worked together – and with an advisory group of experienced high school teachers and administrators – to design an innovative teacher-preparation program designed around the following ideas and principles:

Ownership. Both the Colleges of Natural Sciences and Education feel that teacher preparation belongs to them, and they work together to fund the program, administer it, and attract and retain students.

Majors in mathematics and science. Every student in UTeach majors in mathematics or science and takes a set of technical courses that differs little, if at all, from the set taken by students continuing on to graduate school.

Completion in four years. All of the UTeach degree plans are possible to complete in four years.

Early and continuous field experience. Within the first six weeks of entering UTeach, students are given the opportunity to deliver their first lessons. The first semester, lessons are in elementary schools and the next semester, in middle schools. In subsequent courses, UTeach students move beyond individual lessons and learn to develop larger instructional units at the high school level. This continuous field experience is a unique characteristic of the UTeach program. The demands of the teaching experience rise steadily until, in their final year, the prospective teachers are given charge of multiple classes.

Involvement of teachers. To implement UTeach, the College of Natural Sciences hired a number of the teachers who helped develop it. They participate in the design and improvement of all courses, arrange students' field experiences and work with a wide network of teachers in the schools to mentor the prospective teachers.

Attention to state and national standards. UTeach focuses on ensuring that prospective teachers fully understand and are capable of implementing state and national content standards.

Revision of professional education sequence. Generic education courses have been replaced by a new sequence of courses aimed at improving prospective teachers' understanding of how to guide classroom instruction and interactions, starting with individual lessons and building to longer-length projects that culminate in student teaching.

Special new courses. Teachers must be able to convey the excitement and significance of science and mathematics to their students. UTeach created new courses that focus on often-neglected yet vital aspects of learning and instruction, such as a course on the history and philosophy of science and mathematics and a course on the nature of research.

University of Georgia's Middle School Science and Math Teacher Education Program

The University of Georgia's Middle School Science and Math Teacher Education Program has emerged as a national model for improving the preparation of middle school science and math teachers.

The program, created in 1986, was collaboratively designed and developed by faculty members of the university's College of Education and College of Arts and Sciences, K-12 teachers, and math and science professionals. It features a rich array of content courses in science and mathematics, each connected to a parallel methods course.

Every science teacher completes 35 quarter hours of science content and 15 quarter hours of science education; each mathematics teacher completes 30 quarter hours of mathematics content and 25 quarter hours of mathematics education. All students also complete science- and math-focused writing courses, and are provided with a variety of practicum and clinical field experiences throughout the program.

The program has won numerous honors and awards, including being named by the National Science Teachers Association as one of the top five teacher-education programs in the United States.

Appendix B:
What Mathematics Do Teachers Have to Do and What Do They Need to Know to Do It?

What Mathematics Do Teachers Have to Do?

- Construct mathematically accurate explanations that are comprehensible and useful for students
- Introduce and use mathematically appropriate and comprehensible definitions
- Represent ideas carefully, mapping between a physical or graphical model, the symbolic notation, and the operation or process
- Interpret and make mathematical and pedagogical judgments about students' questions, solutions, problems and insights (both predictable and unusual)
- Be able to respond productively to students' mathematical questions and curiosities
- Make judgments about the mathematical quality of instructional materials and modify as necessary
- Be able to pose good mathematical questions and problems that are productive for students' learning
- Assess students' mathematics learning and take next steps

What Mathematics Do Teacher Need to Know to Do Those Things?

In general:

- Topics and ideas that are fundamental to the school curriculum – and beyond
- Tools and skills for reasoning about mathematical claims, ideas, representations, and solutions; and sensibility about what constitutes adequate proof
- Fluency and care with mathematical language and notation
- Familiarity with applications of mathematics

What provides mathematical leverage?

Topics

- Concepts of number and place value notation
- Operations
- Number theory and number systems
- Common algorithms and how and why they work
- Concepts and tools of algebra
- Geometric concepts and reasoning
- Concepts and tools of statistics and probability

Practices

- Representing and connecting representations (e.g., symbols, graphs, geometric models)
- Mathematical language and definitions
- Mathematical reasoning and justification
- Good sense about mathematical precision and estimation
- Mathematical curiosity and interest

Source: Bass, H. and Ball, D., *What Mathematics Do Elementary and Middle School Teachers Need to Know?*, Presentation at a conference sponsored by the Education Policy Center at Michigan State University, Washington D.C., June 2, 2004.