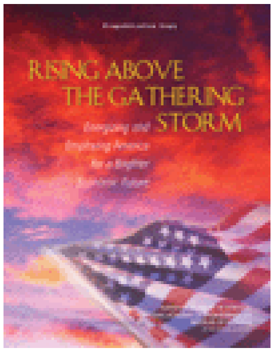

Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future

Committee on Prospering in the Global Economy of the 21st Century:An Agenda for American Science and Technology, National Academy of Sciences, National Academy of Engineering, Institute of Medicine

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10,000 TEACHERS, 10 MILLION MINDS AND K–12 SCIENCE AND MATHEMATICS EDUCATION

Recommendation A: *Increase America's talent pool by vastly improving K–12 science and mathematics education.*

The US system of public education must lay the foundation for developing a workforce that is literate in mathematics and science, among other subjects. It is the creative intellectual energy of that workforce that will drive successful innovation and create jobs for all citizens.[1]

In 1944, during the final phases of a global war, President Franklin D. Roosevelt asked Vannevar Bush, his White House director of scientific research, to study areas of public policy having to do with science. The president observed that, "New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness and drive with which we have waged this war, we can create a fuller and more fruitful employment and a fuller and more fruitful life." In the intervening years, our country appears to have lost sight of the importance of scientific literacy for our citizens, and it has become increasingly reliant on international students and workers to fuel our knowledge economy.

The lack of a natural constituency for science causes short- and long-term damage. Without basic science literacy, adults cannot participate effectively in a world increasingly shaped by science and technology. Without a flourishing scientific and engineering community, young people are not motivated to dream of "what can be," and they will have no motivation to become the next generation of scientists and engineers that can address persistent national problems including national and homeland security, health care, the provision of energy, the preservation of the environment, and the growth of the economy.

Laying a foundation for a scientifically literate workforce begins with developing outstanding K–12 teachers in science and mathematics.[2] A highly qualified corps of teachers is a critical component of the No Child Left Behind initiative.[3] Improvements in student achievement are solidly linked to teacher excellence, the hallmarks of which are thorough knowledge of content, solid pedagogical skills, motivational abilities, and career-long opportunities for continuing education.[4] Excellent teachers inspire young people to develop analytical and problem-solving skills, the ability to interpret information and communicate what they learn, and ultimately to master conceptual understanding. Simply stated, teachers are the key to improving student performance.

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[1] For an alternative point of view on K-12 education reform, see Box 5-1.
[2] See for example, the Glenn Commission Report. 2000. Before It's Too Late A Report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century. U.S. Department of Education Washington, DC.
[3] Department of Education; http://www.ed.gov/nclb/landing.jhtml?src=pb.
[4] National Research Council. 2002. Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. Schools. National Academies Press, Washington D.C.

Box 5-1: An Alternative Point of View: K-12 Education

Some of those who provided comments to the committee questioned the ability of K-12 reform based on the existing US educational model to produce effective, long-lasting improvements in the way our children learn. The United States currently spends more per student than all but one other country (Switzerland),[5] but it is losing ground in educational performance. Its relatively low student achievement through high-school clearly shows that the system is inefficient, and dedicating additional funding to this system will not guarantee success. In fact, the biggest concerns involve disparate quality among K-12 institutions and the difficulty we have with measuring success.

Some question whether K-12 education in the United States really suffers from low student achievement. International comparisons might serve merely to highlight the huge funding inequities among US school districts.[6] American scholastic achievement, unlike that in most other western nations, varies widely from school to school and even from state to state. Eighth graders in high-achieving states score even in mathematics with those in the highest-achieving foreign countries. Some in other states score about even with school children in scarcely developed nations. In the United States, many more suburban school districts can provide smaller classes, better-paid teachers, and more computers than can the schools for most urban and rural children. The underprivileged groups struggle with gross overcrowding, decayed buildings, and inadequate funding even for basic instruction. Standardized test scores generally reflect the disparate distribution of resources.

Some commentators also argued that in industrialized countries there is no correlation between school achievement and economic success but that educational reforms often are the least controversial way of planning social improvement.[7] School changes are less threatening than are direct structural changes, which can involve confronting the whole organization of industry and government. Reforming education, it is claimed, is easier and less expensive than examining and correcting the societal problems that affect our schools directly—the slackening economy, wealth and income inequality, an aging population, the prevalence of violence and drug abuse, and the restructuring of work.

Because there is not a well-developed literature on the effectiveness of K-12 learning and teaching interventions, it is challenging to recommend tried and true programs. For example, some have argued that advanced placement (AP) curriculum needs better quality control and standardization[8], while at the same time programs relying on AP courseware show dramatic effects on student learning. Others have suggested that summer teacher education programs are merely vehicles for textbook companies, and yet others argue that any teacher education programs are worthless unless there is a strong in-classroom, ongoing mentoring component.

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[5] OECD. 2005. Education at a Glance 2005. Paris: Organisation for Economic Cooperation and Development. See http://www.oecd.org/dataoecd/41/13/35341210.pdf.

[6] D.C. Berliner and B.J. Biddle. 1995. The Manufactured Crisis: Myths, Fraud, and the Attack on America's Public Schools. New York: Addison-Wesley.

[7] D.C. Berliner and B.J. Biddle. 1995. Ibid.

[8] National Research Council. 2002. Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. Schools. Washington, DC: National Academy Press.

Today there is such a shortage of highly qualified K–12 teachers that many of the nation's 15,000 school districts have hired uncertified or underqualified teachers. Too many mathematics and science teachers do not have the education, motivation, or materials needed to inspire their students in the classroom (Table 5-1). Moreover, middle and high school mathematics and science teachers are more likely than not to teach outside their own fields of study. A US high school student has a 70% likelihood of being taught English by a teacher with a degree in English but about a 40% chance of studying chemistry with a teacher who was chemistry major.

These problems are compounded by chronic shortages in the teaching workforce. About two-thirds of the nation's K–12 teachers are expected to retire or leave the profession over the coming decade, so the nation's schools will need to fill between 1.7 million and 2.7 million positions during that period of time,[9] about 200,000 of them in secondary science and mathematics classrooms.[10]

TABLE 5-1: Students in US Public Schools Taught by Teachers with No Major or Certification in the Subject Taught, 1999–2000

Discipline	Grades 5–8	Grades 9–12
English	58%	30%
Mathematics	69%	31%
Physical science	93%	63%
Biology–life sciences	—	45%
Chemistry	—	61%
Physics	—	67%
Physical education	19%	19%

SOURCE: National Center for Education Statistics. 2003. *Qualifications of the Public School Teacher Workforce: Prevalence of Out-of-Field Teaching 1987-1988 to 1999-2000.* Washington, DC: US Department of Education.

We need to recruit, educate, and retain excellent K–12 teachers who fundamentally understand biology, chemistry, physics, and mathematics. The critical lack of technically trained people in the United States can be traced directly to poor K–12 mathematics and science instruction. Few factors are more important than this if the United States is to compete successfully in the 21st century.

The Committee on Prospering in the 21st Century recommends a package of K–12 programs that is based on tested models, including financial incentives for teachers and students and high standards for, and measurable achievement from, teachers and students. The programs will create broad-based academic leadership for K–12 mathematics and science, and they will provide for rigorous curricula. Support for the action items in this recommendation should be a priority for the federal government.

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[9] National Center for Education Statistics. 1999. *Predicting the need for newly hired teachers in the United States to 2008–09* (NCES 1999-026). Washington, DC: US Government Printing Office. Available at http://nces.ed.gov/pubs99/1999026.pdf. According to the Bureau of Labor Statistics, job opportunities for K–12 teachers over the next 10 years will vary from good to excellent, depending on the locality, grade level, and subject taught. Most job openings will be attributable to the expected retirement of a large number of teachers. In addition, relatively high rates of turnover, especially among beginning teachers employed in poor, urban schools, also will lead to numerous job openings for teachers. Competition for qualified teachers among some localities will likely continue, with schools luring teachers from other States and districts with bonuses and higher pay. See http://stats.bls.gov/oco/ocos069.htm#emply.

[10] National Research Council. 2000. *Attracting science and mathematics Ph.D.s to secondary school education.* Washington, DC: National Academy Press. Available at http://www.nap.edu/catalog/9955.html.

The strengths of the proposed actions derive from their focus on *teachers*—those who are entering the profession and those who currently teach science and mathematics—*and on the students they will teach*. The recommendations cover the spectrum of K–12 teachers, and several programs are recommended to tailor education for different populations. Each recommendation has specific, measurable objectives. At the same time, we must emphasize the need for research and evaluation to serve as a foundation for change in K–12 mathematics and science education. In particular, a better understanding of what actions can be taken to excite children about science, mathematics, and technology would be useful in designing future educational programs.

The first two action items focus on K–12 teacher education and professional development: Give new K–12 teachers a solid science, mathematics, and technology foundation, provide continuing professional development for current teachers and for those entering the profession from technology sector jobs so they gain mastery in science and mathematics and the means to teach those subjects, and finally provide continuing education for current teachers in grades 6–12 so they can teach vertically aligned advanced science and mathematics courses.[11] One fortunate spin-off of enhanced education of K–12 teachers is that salaries—in many school districts—are tied to teacher educational achievements.

TEN THOUSAND TEACHERS FOR TEN MILLION MINDS

Action A-1: Annually recruit 10,000 science and mathematics teachers by awarding 4-year scholarships and thereby educating 10 million minds. Our public education system must attract at least 10,000 of our best college graduates to the teaching profession each year. A competitive federal scholarship program would allow bright, motivated students to earn bachelors' degrees in science, engineering, and mathematics with concurrent certification as K–12 mathematics and science teachers.

Students could enter the program at any of several points and would receive annual scholarships of up to $20,000 per year in the program for tuition and qualified educational expenses. Awards would be given on the basis of academic merit.[12] Each scholarship would carry a 5-year postgraduate commitment to teach in a public school.[13] The annual investment in such scholarships at steady state would be $400 million to $800 million.

To provide the highest quality education for students who want to become teachers, it is important to award competitive matching grants of $1 million per year for 5 years to help 100 universities and colleges establish integrated 4-year undergraduate programs that lead to bachelors' degrees in science, technology, engineering, or mathematics (STEM) with teacher

[11] "Vertically aligned curricula" use sequenced materials over several years. An example is pre-algebra followed by algebra, geometry, trigonometry, pre-calculus, and calculus. The systematic approach to education reform emphasizes that teachers, school and district administrative personnel, and parents work together to align their efforts. See, for example, SEDL. 2004. *Alignment in SEDL's Working Systemically Model, 2004 Progress Report to Schools and Districts.* Southwest Education Development Laboratory, Austin, TX. Available at http://www.sedl.org/rel/resources/ws-report-summary04.pdf.

[12] Teacher education programs would be 4-years in duration with multiple entry points. A first-year student entering the program would be eligible for a 4-year scholarship, while students entering in their second or later undergraduate years would be eligible for fewer years of support. If all those who were awarded the scholarship were first-year students, the annual cost of scholarships would be $400 million (without administrative costs).

[13] If the scholarship recipient does not fulfill the 5-year service requirement, they would be obligated to repay a pro-rated portion of their scholarship. Recipients who work in underserved school districts would be required fewer years of service to fulfill their scholarship obligation.

certification.[14] To qualify, STEM departments would collaborate with colleges of education to develop teacher education and certification programs with in-depth content education and subject-specific education in pedagogy. STEM departments also would offer high-quality research experiences and thorough training in the use of educational technology. Colleges or universities without education departments or schools could collaborate with such departments in nearby colleges or universities.

A well-prepared corps of teachers is central to the development of a literate student population.[15] The National Center for Teaching and America's Future unequivocally shows the positive effect of better teaching on student achievement.[16] The Center for the Study of Teaching[17] reported that the most consistent and powerful predictor of student achievement in science and mathematics was the presence of teachers who were fully certified and had at least bachelor's degrees in the subjects taught. Teachers with content expertise, like experts in all fields, understand the structure of their disciplines and have cognitive "roadmaps" to the work they assign, the assessments they use to gauge student progress, and the questions they ask in the classroom.[18] The investment in educating those teachers is money well spent because they are likely to prepare internationally competitive students.

Some of the nation's top research universities are leading the way to prepare a cadre of highly skilled teachers. Two in particular have developed innovative programs that combine undergraduate degrees in science, technology, engineering, or mathematics with pedagogy education and teacher certification.

UTeach,[19] a program at the University of Texas at Austin, recruits undergraduate science and mathematics students, 25% of whom express a serious desire to teach. Program enrollees have SAT scores above the average for the university's College of Natural Sciences (CNS), have higher grade point averages, and are retained in the degree program at more than twice the rate of other CNS students (Figure 5-1). UTeach has a 26% minority enrollment, compared with 16% university-wide. Each year the program graduates about 70 students who have teaching certification and bachelors' degrees in chemistry, physics, computer science, biology, or mathematics. Students receive strong practical education and continuing mentoring, especially in the critical first few years in the classroom, as that increases effectiveness and promotes

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[14] The institutional awards would be matching grants awarded competitively to applicants who had identified partners to contribute additional resources, such as universities, industries, or philanthropic foundations. Public-public and public-private consortia would be encouraged. Institutions that demonstrate success would be eligible for competitive renewals.
[15] NRC. 2002. Attracting PhDs to K–12 Education: A Demonstration Program for Science, Mathematics, and Technology. National Academies Press, Washington, DC.
[16] National Center for Teaching and America's Future. 1996. *Doing what matters most: Teaching for America's future*. New York: NCTAF.See also H.C. Hill, B. Rowan, and D.L. Ball. 2005. Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal 42*(2): 371-406.
[17] L. Darling-Hammond, 1999. *Teacher quality and student achievement: A review of state policy evidence*. New York: Center for the Study of Teaching and Policy. Available at http://depts.washington.edu/ctpmail/Publications/PDF_versions/LDH_1999.pdf.
[18] National Research Council. 1999. *How people learn: Brain, mind, experience, and school.* Bransford, John D., Brown, Ann L., and Cocking, Rodney R. (Eds.). Committee on Developments in the Science of Learning. Washington, DC: National Academy Press. Available at http://books.nap.edu/catalog/6160.html.
[19] Teachers for a New Era is a similar undergraduate program, based solely within university and college education departments. Among its guiding principles are top-level collaboration between university faculty in the arts and sciences with the school of education faculty to ensure that prospective teachers are well grounded in specific disciplines and provided a liberal arts education and the establishment of teaching as a profession responsible for the cognitive development of students. Master teachers mentor students in a formal 2-year residency as they make the transition from college to classroom. See http://www.teachersforanewera.org/. The National Academies has also published a report on demonstration programs for PhD K–12 teacher programs, National Research Council. 2002. *Attracting PhDs to K–12 Education: A Demonstration Program for Science, Mathematics, and Technology.* National Academies Press, Washington, DC.

professional retention. UTeach graduates have deep disciplinary grounding, they know how to engage students in scientific inquiry, and they know how to use new technology to improve student achievement. The UTeach experience shows that an effective scholarship program must be coupled with a teacher education program that is interesting and attractive to students. The program's most effective tools are the field experience courses for first-year students and the use of master teachers as their supervisors.

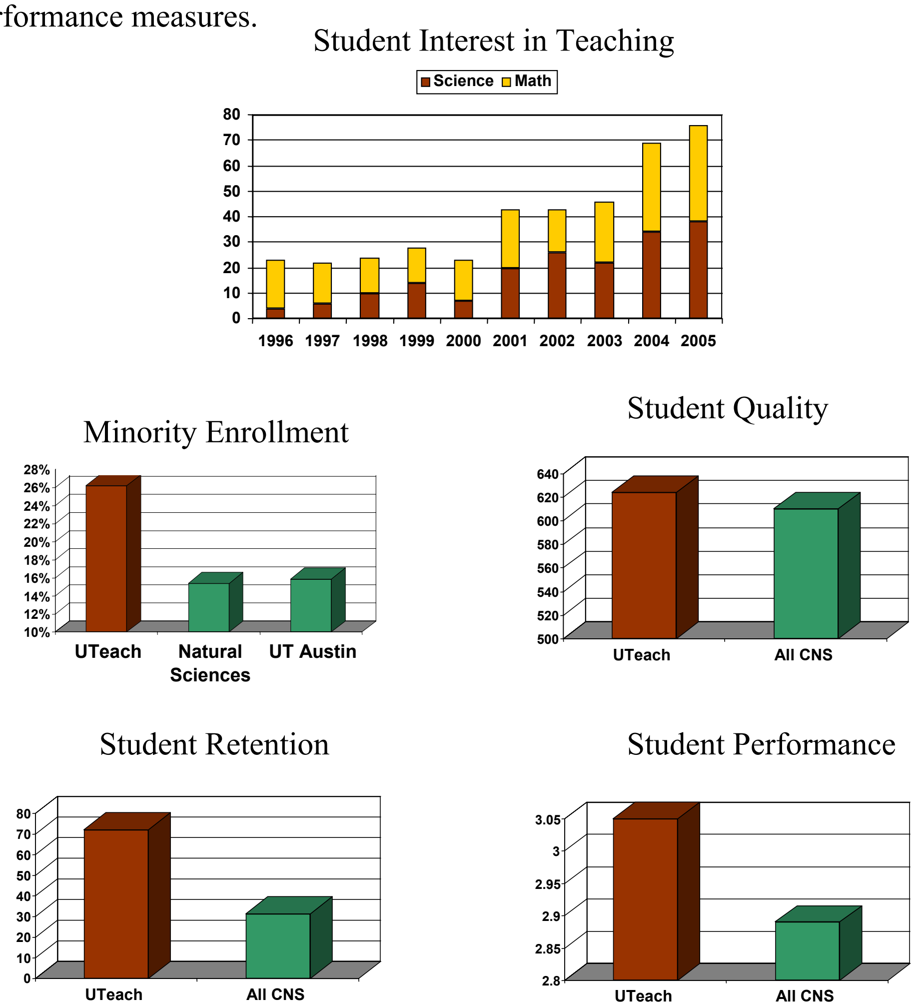
Starting with the current academic year, the 10-campus University of California (UC) system offers its California Teach program, which, by 2010, should graduate a thousand highly qualified science and mathematics teachers each year.[20] California Teach provides every STEM student in the university with an opportunity to complete the STEM major and pedagogical training in a 4-year program. Early in the program, students work as paid classroom assistants in elementary and middle schools, supervised by mentor teachers. Students enroll in seminars taught by master teachers and participate in 10-week summer institutes to help them develop methods for teaching in a specific discipline. Students from throughout the university system in the California Teach program who satisfactorily complete their courses through the junior year participate in subject-area institutes. UC San Diego, for example, might host a high school chemistry institute that would be open to students and faculty from all campuses.

At each institute, students and faculty (those from UC, those who are visiting, and master secondary school teachers) collaborate to develop case study videos of teaching methods and approaches that will be archived by UCTV for use by students and faculty in subsequent institutes and by teachers in the field. Students develop the portfolios that eventually will be required of teachers to become certified by a national board. Students who complete the institutes receive $5,000 scholarships.

Both the UTeach and California Teach programs provide a continuum of pre- and in-service teacher education and professional development and established cohorts and relationships that are crucial for retaining the most talented individuals in the profession. California Teach also will provide the nation with a large-scale experiment to show which elements of teacher preparation are most effective. Replicating such programs around the country will transform the quality of our science and mathematics teaching.

[20] Even more teachers may come from a similar program being conducted by the California State University system.

FIGURE 5-1 UTeach enrollment, quality of undergraduate students in the program, and performance measures.



* Minority enrollment does not include students identified as Ca ucasian, Asian, or foreign.
§ Retention for CNS (College of Natural Sciences) is based on 6 year graduation rate. Retention for UTeach students is based on those completing Step 1 course who then go on and complete the entire program.

A QUARTER OF A MILLION TEACHERS INSPIRING YOUNG MINDS EVERY DAY

Action A-2: Strengthen the skills of 250,000 teachers through training and education programs at summer institutes, in Master's programs, and Advanced Placement and International Baccalaureate (AP and IB) training programs and thus inspires students every day. Excellent professional development models exist to strengthen the skills of the 250,000 current mathematics and science teachers, but they reach too few in the profession. The four-part program recommended by the committee consists of (1) summer institutes, (2) master's degree programs in science and mathematics, (3) training for advanced placement and International Baccalaureate (IB) instructors, and (4) development of a voluntary national K–12 science and mathematics curriculum.

We need to reach all K–12 science and mathematics teachers and provide them with high-quality continuing professional development opportunities—specifically those that emphasize rigorous content education. High-quality, content-driven professional development has a significant effect on student performance, particularly when augmented with classroom practice, year-long mentoring, and high-quality curricular materials.[21]

About 10% of the nation's 3 million K–12 teachers provide instruction in science and mathematics in middle-school and high-schools.[22] No Child Left Behind requires all of them to participate regularly in professional development, and, in most states, professional development already is required to maintain teaching credentials. Funding for continuing education now comes from the No Child Left Behind appropriation and from the states. As the number of programs has ballooned; many teachers report that they are "buried in opportunities" for continuing education They also complain that it is difficult to know which programs are worthwhile and which are irrelevant and disconnected. The object of this action is to define high-quality mechanisms that can be implemented to sharpen content knowledge and pedagogy skills, especially for those who enter the profession from other careers. Over 5 years, these programs could reach all teachers of middle and high school mathematics and science.

Action A-2 Part 1: Summer Institutes

The first implementation action mechanism is a program of summer education for 50,000 classroom teachers each year. Matching grants would be provided to state and regional summer institutes to develop and provide 1- to 2-week sessions. The expected investment per participant is about $1200 per week, excluding participant stipends, which would be covered by local school districts.

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[21] D.K. Cohen and H.C. Hill. 2000. Instructional policy and classroom performance: The mathematics reform in California. *Teachers College Record* 102(2): 294-343;
W.H. Schmidt, C. McKnight, R.T. Houang; and D.E. Wiley. 2005. The Heinz 57 curriculum: When more may be less. *Paper presented at the 2005 annual meeting of the American Education Research Association*, Montreal, Quebec. NRC. 2001. *Educating Teachers of Science, Mathematics, and Technology: New Practices for a New Millennium.* National Academies Press, Washington, DC;
NRC. 1997.
Improving Teacher Preparation and Credentialing Consistent with the National Science Education Standards: Report of a Symposium. National Academy Press, Washington DC; and NRC. 1997.
[22] In 1999-2000, the latest year for which we have figures, of the total number of public K–12 teachers, 191,000 taught science (including biology, physics, and chemistry) and 160,000 taught mathematics.

Summer institutes for secondary school teachers of science and mathematics have existed in various forms at least since the 1950s, often with corporate sponsors.[23] The National Science Foundation (NSF) started funding teacher institutes in 1953, when shortages of adequately trained personnel in scientific and technical fields became increasingly evident.[24] In 2004, the NSF Math and Science Partnership began making awards under a new program, Teacher Institutes for the 21st Century.[25]

There is a strong need for elementary and middle school teachers to have a deeper education in science and mathematics.[26] Many school children are systematically discouraged from learning science and mathematics because of their teachers' lack of preparation, or in some cases, because of their teachers' disdain for science and mathematics. Because of the large amount of time that is devoted to standards-based testing in reading and mathematics, just 16 minutes each day is spent on science in most of the nation's public K–6 classrooms. In many schools, no science at all is taught before middle school.

Teachers who are not required to teach science have little reason to increase their knowledge and skills through professional development. No Child Left Behind requirements, however, will expand testing to the sciences in 2007. Elementary school teachers thus need training now in many areas of science; they need to see the relationships between mathematics and the sciences; and, most important, if they are to excite young minds, they need the ability to integrate information across disciplines. In short, teachers need to be scientifically literate and preferably to be excited about teaching science.

The Merck Institute for Science Education (MISE)[27] is an in-service professional development program for K–6 teachers established in 1993 with a 10-year commitment from Merck & Company. An intensive 3-year course combines multiple-year summer institutes in inquiry-based science instruction that is tied to state and national standards with in-classroom follow-up and reinforcement from September to June. MISE also provides curriculum materials and training in their use. The current participants are K–6 teachers in New Jersey and Pennsylvania public schools. In all, about 4000 teachers have participated in the program. Analysis by an external evaluator indicates that students of teachers who participated in MISE professional development programs for at least 3 years outperformed those whose teachers participated for a year or less.[28]

Local MISE programs have made science a priority in each district. New science frameworks and instructional materials developed by MISE have been adopted by all of the

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[23] Summer institutes at Union College in Schenectady and at the Case Institute of Technology in Cleveland were supported by the General Electric Company, institutes at the University of Minnesota were supported by the Ford Foundation, and institutes at the University of Tennessee were supported by the Martin Marietta Corporation.

[24] Funding for institutes for the continuing education of high school science teachers began to decline in number in the late 1960s, when the shortages of technical personnel including science teachers, began to decline. After a leveling period during the 1970s, NSF support for teacher institutes was discontinued in 1982. Support for the teacher institute programs was resumed the following year following several national reports detailing the severe problems facing science teaching and with growing recognition of the shortage of qualified science teachers.

[25] These awards are directed to disciplinary faculty of higher education institutions to work with experienced teachers of mathematics and the sciences to deepen teachers' content knowledge and instructional skills so they may become school-based intellectual leaders in their fields.

[26] National Research Council. 1997. Science for All Children: A Guide to Improving Elementary Science Education in Your School District. National Academy Press, Washington DC.

[27] http://www.mise.org/mise/index.jsp.

[28] Consortium for Policy Research in Education. 2002. *A Report on the Eighth Year of the Merck Institute for Science Education.* CPRE, University of Pennsylvania, Philadelphia, PA, available at http://www.mise.org/pdf/cpre2000_2001.pdf. When MISE was created in 1995, there were no district-wide or state assessments in science in Pennsylvania or New Jersey, where MISE programs were based. The absence of assessment often meant that less attention was given to science in elementary classrooms, and it meant that there was no easy way to measure the impact of MISE's work on student learning. MISE has been exploring the use of performance tasks for district-wide assessment. For the past two years, performance tasks drawn from the Third International Mathematics and Science Study (TIMSS) have been administered in grades 3 and 7 in all four districts. This has been a collaborative project involving MISE staff, central office staff, and many interested teachers.

participating districts. Added benefits are seen in the improvements in hiring and recruitment of teachers and administrators, increased expenditures for instructional materials, changes in how teachers are observed and evaluated in the classroom, augmented instructional support services, development of new district wide science assessments, and the leveraging of significant additional external resources for science education programs. MISE also has helped to lead the way in the creation of statewide science content standards and professional development standards.

Similar to MISE in its focus on K–6 science education is the Washington State Leadership and Assistance for Science Education Reform (LASER) program,[29] which began in 1999 with a strategic planning institute to coordinate standards, curricula, and evaluation. Six more institutes have convened since then, and now 131 school districts which enroll more than 60% of Washington's students, are at various stages of implementing an inquiry-based science program.[30]

In 2005, achievement in the 5th-grade science portion of the Washington Assessment of Student Learning (WASL) was measured and correlated with teacher participation in LASER. Primary among the findings was a significant relationship between professional development among teachers and the percentage of students meeting the science standard on the 2004 test (Figure 5-2). LASER teachers' classroom practices changed incrementally until they had more than 80 hours of professional development; at that point, more dramatic shifts to inquiry-based methods were observed.

[29] Washington LASER, http://www.wastatelaser.org/.

[30] Inquiry is a set of interrelated processes by which scientists and students pose questions about the natural world and investigate knowledge. Using an inquiry-based approach students learn science in a way that reflects how science actually works. See NRC. 1995. *National Science Education Standards.* Washington, DC: National Academy Press.

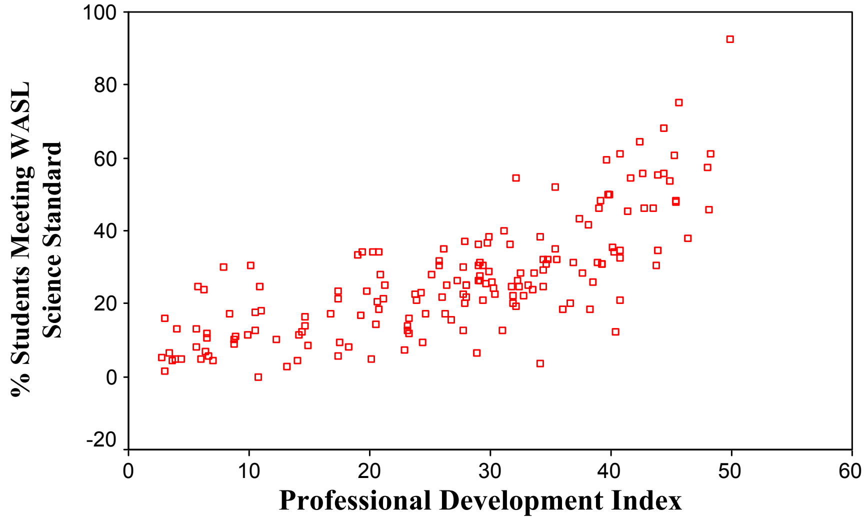

FIGURE 5-2 Professional development of teachers increases student achievement in science. The scatter plot shows the PD index (total professional development hours per 100 students provided over a 3-year period to the teachers of 5th graders who took the WASL in spring 2004) compared with the percentage of students who met the WASL standards. Each box represents a school. There is a gradual increase in the percentage of students meeting the standard as the PD index increases. The data suggest the rate of increase accelerated after teachers received a critical amount of professional development, although the exact point at which that change occurred cannot be determined without access to classroom-level aggregates and the ability to track the professional development of the teachers of individual students. The relationship between professional development and student achievement holds even after adjustments for the influence of percentage of students eligible for free and reduced lunches and for the percentage of Asian students.

SOURCE: D. Schatz, D. Weaver, and P. D. Finch. *Washington State LASER — Evaluation Results* (in preparation).

The system of national laboratories also can be tapped for continuing education of K–12 teachers. The Laboratory Science Teacher Professional Development program was designed by the Office of Science in the Department of Energy (DOE) to create a cadre of outstanding middle- and high-school science and mathematics teachers who will serve as leaders in their local and regional teaching communities.[31] Through this 3-year program, teachers establish long-term relationships with DOE mentor scientists and with teaching colleagues. Teachers are expected to spend at least 4 weeks at one of the DOE laboratories during the first year and at least 2 weeks at one of the laboratories for each of 2 years after that. If such a program were used to train 2 teachers from each of the 16,000 school districts in the country over a 10-year period, about 3200 teachers each year would be brought into the 17 DOE laboratories, eventually reaching a 3-year steady state of 9600 teachers. The Secretary of Energy Advisory Board Science and Mathematics Education Task Force is currently reviewing such a proposal.[32]

Action A-2 Part 2: Science and Mathematics Masters' Programs

The second implementation step mechanism would reach 50,000 teachers in 5 years. It would provide 500 competitive institutional grants each year to develop part-time 2-year master's degree programs (3 full-time summers plus alternate weekends during the academic year) in science and mathematics education for current teachers. The programs would focus on content education and pedagogy and provide in-classroom training and continuous evaluation for in-service middle- and high-school teachers and career changers. The program would require an investment of about $500 million each year.[33]

The program's master teachers[34] would provide leadership in their own districts for all the programs included in this recommendation: They would be mentors for new college graduates teaching in their schools and for the many very able current teachers who would welcome the opportunity to upgrade their skills through summer institutes or education to become Advanced Placement and International Baccalaureate (AP–IB) and pre-AP–IB teachers. Teachers who complete the program would receive incentive stipends of $10,000 annually, for as long as they remain in the classroom and engage in leadership activities.[35]

Students learn best from teachers who have strong content knowledge and pedagogical skills.[36] Unfortunately, it is uncertain what science and mathematics preparation, beyond the basics, will be the best training for teachers. Nonetheless, it is known that they will need to stay

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[31] http://www.scied.science.doe.gov/scied/LSTPD/about.htm
[32] http://www.seab.energy.gov/sub/committees.htm
[33] Program funds would provide up to $1 million per year over 5 years per program and would cover: development of course ($100,000/program), hiring of professional staff to run the program ($500,000/program), equipment funds for computer and teaching aids ($50,000/program), education of at last 20 teachers/program/year, with stipend support to the participants in the form of tuition reimbursement ($20,000/student) and travel expenses ($1,500/student). Programs that demonstrate success would be eligible for competitive renewals. Implementation of online courseware to engage in-service teachers should be a high priority.
[34] This program may be even more effective if such master teachers would be Nationally Board Certified, and would then become a national pool of teacher leaders.
[35] Such Master teachers should also be eligible for some release time from classroom teaching to engage in leadership activities.
[36] National Research Council. 2002. Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. Schools. National Academies Press, Washington D.C.
M. Cochran-Smith and K.M. Zeichner. 2005. *Studying teacher education.* American Educational Research Association, Washington, DC;. Michael Allen. 2003. *Eight Questions on Teacher Preparation: What does the Research Say?* Education Commission of the States, Washington, DC, available at http://www.ecs.org/tpreport.

current with their disciplines. Master's degree programs, particularly those emphasizing content knowledge, keep teachers updated and provide the skills to teach for the future.

The Science Teacher Institute in the University of Pennsylvania's School of Arts and Sciences and Graduate School of Education [37] is a rigorous program that trains middle- and high-school science teachers. Eighty percent of the education is in a participant's scientific discipline and 20% percent is in pedagogy, emphasizing the secondary-classroom applications of inquiry-based instruction. At the end of 2 years (3 summers and alternate Saturdays during the school year), teachers graduate with master degrees in chemistry education or integrated science education. Those teachers have a major influence in their schools.[38] They mentor other teachers, update the schools' curricula, and recruit students into demanding science courses. They are the "teachers of teachers" who provide the academic leadership so urgently needed in school districts across the country.

An additional 50,000 of those truly outstanding teachers could inspire and support students and other teachers to work harder at mathematics and science. Our recommendation would provide the funding and structure to reach about one-sixth of the nation's science and mathematics teachers—about 3 teachers in each of the nation's over 15,000 school districts.

Action A-2 Part 3: Advanced Placement, International Baccalaureate, and Pre-AP–IB Education

The third implementation step mechanism is a program to train an additional 70,000 AP–IB and 80,000 pre-AP–IB teachers of mathematics and science, phasing in 30,000 newly qualified teachers in each of 5 years. Teachers from schools where there are few or no AP–IB courses would receive priority for this program. The program model is the College Board's AP program, which has wide acceptance in secondary and higher education. It also could be implemented in schools certified by the International Baccalaureate organization. Implementation in each state would require the creation of a non-profit organization staffed by talented master teachers who would help local schools manage the program and enforce high standards.[39] Assuming satisfactory performance, AP–IB teachers would receive incentives to attend professional development seminars and to tutor and prepare students outside regular classroom hours under the present proposal. Their development fees would be paid and they would receive a bonus for each student who passed an AP or IB exam in mathematics or science.

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[37] Science Teacher Institute, http://www.sas.upenn.edu/PennSTI/.

[38] C. Blasie and G. Palladino. 2005. Implementing the Professional Development Standards: A Research Department's Innovative Masters Degree Program for High School Chemistry Teachers. *Journal of Chemical Education* 82(4): 567-570.

[39] The total 5-year cost for 70,000 AP/IB teachers is $954 million: $224 million for professional development; $504 million in annual stipends; $226 million in bonuses for passing scores. Pre-AP/IB teacher cost is $364 million: $248 million in development fees and $116 million for passing scores. This brings the total five year cost to train and reward 150,000 teachers to $1.3 billion.

The model for this recommendation is the Dallas-based AP Incentive Program (APIP),[40] which offers financial incentives to prepare instructors to teach demanding courses that will train ever-increasing numbers of secondary school students. To serve as large a percentage of students as possible, APIP has been coupled with a pre-AP program, Laying the Foundation, which begins in the 6th grade to help students prepare for 11th- and 12th-grade AP and IB examinations. Teachers use vertically aligned lessons based on national standards and final, comprehensive exams to measure mastery of essential concepts. The process continues through middle and high schools to assure that graduating seniors are prepared for college work.

The foundation for each program is intensive, 4-year professional development delivered by the College Board and by master teachers in local school districts.[41] Assuming satisfactory performance, teachers can receive annual incentive payments of up to $1800, paid for by a group of foundation and industry donors. Teachers also receive a $100 bonus for each student who passes an AP exam in mathematics or science.

To reach currently underserved areas or populations of students with specific learning needs, it might be useful to consider implementing online learning. The University of California College Prep program (UCCP) makes AP courses available to students who enroll individually or as part of a school group. In either case, they have online access to teachers and tutors. The more than 5000 students currently enrolled are taught by certified teachers and tutored by paid university undergraduates and graduate students.

Action A-2 Part 4: K–12 Curricular Materials Modeled on World-Class Standards

The fourth part of the K–12 recommends that the Department of Education would convene a national panel to collect proven effective K–12 science and mathematics teaching materials or develop new ones where no effective models exist. All materials would be made available online, free of charge, as a voluntary national curriculum that would provide an effective standard for K–12 teachers at a cost of about $100 million over 5 years.

High-quality teaching is grounded in careful vertical alignment of curricula, assessments, and student achievement standards. Efforts to directly evaluate curricular quality have foundered in the past,[42] but the need still exists. Excellent resources for the development of K–12 science, technology, and mathematics curricular materials include the National Academies' Science

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[40] APIP is part of a statewide initiative to raise educational standards. See Texas Education Agency. 2003. *Advanced Placement and International Baccalaureate examination results in Texas, 2001-02* (Document No. GE03 601 08). Austin, TX: TEA. In 2001, the Texas Legislature enacted the Gold Performance Acknowledgement (GPA) system to acknowledge districts and campuses for high performance on indicators not used to determine accountability ratings (TEC, §39.0721, 2001). Included is an AP-IB indicator that measures the percentage of non-special-education students who take an AP or IB examination and the combined percentage of non-special-education examinees at or above the criterion score on at least one AP or IB examination (TEC §39.0721, 2001). The percentage of examinations with high scores on AP or IB was kept as a report-only performance indicator (TEA, 2002e). GPA acknowledgement is given when non-special-education 11th and 12th graders take at least one AP or IB examination represent 15% or more of the non-special-education in 11th and 12th grade students and 50% or more of those examinees have at least 1 score of 3 or above on an AP examination or 4 or above on an IB examination.

[41] Professional development for AP teachers includes attending the College Board's week-long summer institute and 2-day seminar in their discipline each year for 4 years ($800/teacher/year). Laying the Foundation education consists of a 4-day summer institute and 4 days on campus each year for 4 years ($775/teacher/year includes education, teacher's guide, lesson plans, laboratory activities; and diagnostic assessments). Master teachers, one for mathematics and one for science for every 3 high schools with an AP or IB program are essential to implement the program and help it grow in each district.

[42] Math and Science Expert Panel. 1999. *Exemplary Promising Mathematics Programs.* Washington DC; US Department of Education; National Research Council. 2004. *On Evaluating Curricular Effectiveness: Judging the Quality of K-12 Mathematics Evaluations.* Washington DC: National Academies Press.

Education Standards;[43] Project 2061;[44] and numerous Web-based compendia, including the National Science Digital Library.[45] Gateway to Educational Materials (GEM), sponsored by the US Department of Education, is a collaborative effort to collect materials and provide them free to educators. The GEM Web site offers more than 20,000 educational resources, catalogued by type and grade level. Although it has been lauded as an exemplary effort, GEM has two shortcomings: GEM is cumbersome to use, and the quality and depth of its resources are in some cases questionable. GEM also has made clear that teacher education programs need to add a technology component.[46]

Project Lead the Way (PLTW) is a national program with partners in public schools, colleges and universities, and the private sector.[47] The project has developed a 4-year sequence of courses that, when combined with college preparatory mathematics and science, introduces students to the scope, rigor, and discipline of engineering and engineering technology. PLTW also has developed a middle-school technology curriculum, Gateway to Technology. Students participating in PLTW courses are better prepared for college engineering programs.

Comprehensive teacher education is a critical component of PLTW, and the curriculum uses cutting-edge technology and software that requires specialized education. Continuing education supports teachers as they implement the program and provides for continuous improvement of skills.

EXPAND THE PIPELINE

Action A-3: Enlarge the pipeline by increasing the number of students who take AP and IB science and mathematics courses. The competitiveness of US knowledge industries will be purchased largely in the K–12 classroom: We must invest in our students' mathematics and science education. A new generation of bright, well-trained scientists and engineers will transform our future only if we begin in the 6th grade to significantly enlarge the pipeline and prepare students to engage in advanced coursework in mathematics and science.

The other side of the classroom equation, of course, is the students,[48] our innovators of the future.[49] Despite expressing their interest, many US students avoid rigorous high-school work in mathematics and science.[50] All US students should be held to high expectations, and rigorous coursework should be available to all students. Particular attention should be paid to increasing the participation of those students in groups that are underrepresented in science, technology, and mathematics education, training, and employment.

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[43] NRC. 1996. *National Science Education Standards*. National Academy Press, Washington, DC; NCTM. 2000. *Principles and Standards for School Mathematics*. Washington DC; National Council of Teachers of Mathematics, http://standards.nctm.org/.
[44] Project 2061, sponsored by the American Association for the Advancement of Science, is an initiative to reform K–12 education nationwide so that all high-school graduates are science literate. In the first stage, of its work, Project 2061 published *Science for All Americans* (SFAA), which outlines what all students should know and be able to do in science, mathematics, and technology after 13 years of schooling. See http://www.project2061.org/default_flash.htm.
[45] http://nsdl.org/.
[46] For example, see: MA Fitzgerald and J McClendon. 2002. The Gateway to Educational Materials: An Evaluation Study, Year 3. A Technical Report Submitted to the US Department of Education (October 10). http://www.geminfo.org/Evaluation/Fitzgerald_02.10.pdf.
[47] PLTW is now offered in 45 states and the District of Columbia. See http://www.pltw.org/aindex.htm.
[48] NRC. 2004. *Engaging Schools: Fostering High-School Students' Motivation to Learn*. National Academies Press, Washington, DC.
[49] K. Hunter. 2005. Education key to jobs, Microsoft CEO says *Stateline.org*, August 17.
[50] T. Lewin. 2005. Many Going to College Are Not Ready, Report Says. *New York Times*, August 17. Among those who took the 2005 ACT, only 51 percent achieved the benchmark in reading, 26 percent in science, and 41 percent in mathematics; the figure for English was 68 percent.

The first goal of the proposed action is to have 1,500,000 students taking at least one AP or IB mathematics or science exam by 2010, an increase to 23% from 6.5% of juniors and seniors who took at least one AP or IB mathematics or science exam in 2004. We also must increase the number of students who pass those exams from 230,000 in 2004 to 700,000 by 2010. AP and IB programs would be voluntary and open to all, and would give students a head start in college-level courses taught by outstanding high-school teachers.[51] The result will be better prepared undergraduates who will have a better chance of completing their bachelors' degrees.[52] Table 5-2 shows that a student who passes an AP exam has a better chance overall—regardless of ethnicity—of completing a bachelor's degree within 6 years. Students would be eligible for a 50% examination fee rebate and a $100 mini-scholarship for each passing score on an AP or IB mathematics or science exam. The 5-year cost for 700,000 students is estimated at $428 million: $202 million for exam fees and $226 million for mini-scholarships.

TABLE 5-2: Six-Year Graduation Rate, Students Who Passed AP Exams and Students Who Did Not Take AP Exams

Ethnicity	Passed AP Exam	Did Not Take AP Exam
White	72%	30%
Hispanic	62%	15%
African American	60%	17%

NOTES: All students graduating from Texas public high schools in 1998 and enrolling in a Texas public college or university (88,961 students). AP exams were given in the core subjects of English, mathematics, science, and social studies to students in grades 10–12. The percentage shown is the proportion of students who obtained bachelors' degrees or higher within 6 years of secondary school graduation. It is notable that participation in AP courses had an impact on graduation rates, even if students did not pass the AP exam. College graduation rates were substantially increased among students who took but did not pass the AP exam (White: 55%, Hispanic, 38%, and African American, 47%).,

SOURCE: National Center for Educational Accountability, http://www.nc4ea.org/

The action is built on standards, testing, and incentives to achieve excellence in science and mathematics. The APIP program has been successful—across gender, ethnicity, and economic groups. The new proposed program would give students the further background they need to study science, engineering, and mathematics as undergraduates.

Such advanced coursework can provide the foundation for students to be internationally competitive. For example, US students who passed AP calculus in 2000 were administered the

[51] One researcher estimates that, each year, 25,000 interested and adequately prepared students in the United States are told they cannot take AP or IB courses. He further speculates that another 75,000 or more students who could do well elect not to take them because no one encourages them to do so. See J. Mathews. 1998. *Class Struggle: What's wrong (and right) with America's best public high schools.* New York: Times Books. Limiting access to advanced study occurs in all kinds of educational settings, including the most competitive high schools in America—schools with adequate resources, qualified teachers, and well-prepared students. Those schools, while typically advocating college preparation for everyone, create layers of curricular differentiation such that only a select group of students are allowed entrance into certain AP and honors courses; other students are placed in less vigorous courses. See Attewell, 2001, The winner take-all high school: Organizational adaptations to educational stratification. *Sociology of Education* 74(4): 267-296. For a larger discussion of access to advanced coursework, see NRC. 2002. *Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. Schools.* National Academies Press, Washington DC.

[52] Academic opportunities such as AP and IB programs benefit students in several ways. High school students who participate in AP and IB courses and associated examinations are exposed to college-level academic content and are challenged to complete more rigorous coursework. Students with qualifying examination scores are provided the opportunity to earn college credit or advanced placement, depending on the college or university they attend. (TEA, 2003).

1995 Trends in International Mathematics and Science Study (TIMMS) test.[53] Their scores were significantly higher than the average 1995 US score, and they were higher than the 1995 average scores of the students from all 14 participating countries. Similarly, US students who passed AP physics in 2000 outperformed the 1995 US national TIMSS average and exceeded the 1995 scores for all participating countries except Norway (Table 5-3).[54] The big question is how such students compare to the top students in other countries. However, it is clear that engaging K-12 students in challenging courses taught by qualified teachers will enhance the educational experience and may increase the number of students who enter college and complete higher education degrees.

TABLE 5-3 Achievement of US AP Calculus and Physics Students Who Took TIMSS in 2000 Compared with Average International Scores from 1995[55]

Mathematics		**Physics**	
	Average Score		Average Score
US AP calculus students scoring 3, 4 or 5	**596**	Norway	581
US AP calculus students taking, but not passing exam	**573**	**US AP physics Students scoring 3, 4, or 5**	**577**
France	557	Sweden	573
Russian Federation	542	Russian Federation	545
Switzerland	533	**US AP physics Students taking, but not passing exam**	**529**
Australia	525	Germany	522
Cyprus	518	Australia	518
Lithuania	516	***International Average***	***501***
Greece	513	Cyprus	494
Sweden	512	Latvia	488
Canada	509	Switzerland	488
International Average	***501***	Greece	486
Italy	474	Canada	485
Czech Republic	469	France	466
Germany	465	Czech Republic	451
United States	**442**	Austria	435
Austria	436	**United States**	**423**

[53] See Chapter 3 or Appendix for more detailed discussion of the exam http://nces.ed.gov/timss/.
[54] At the same time, the National Research Council has called for the College Board to "exercise greater quality control over the AP trademark by articulating standards for what can be labeled an AP course, desirable student preparation for each course, strategies for ensuring equity and access, and expectations for universal participation in the AP examinations by course participants." National Research Council. 2002. *Learning and Understanding: Improving Advanced Study of Mathematics and Science in US High Schools.* Washington, D.C:. National Academies Press.
[55] Advanced Placement scores on a 5-point scale. 3 is considered a passing score by the College Board, the organization that administers the courses. Most colleges and universities require a score of 4 or 5 to qualify for course credit.

Data from the Texas APIP demonstrate that combining incentives and teacher education can increase student participation (Figure 5-3), and APIP has decreased the performance gap for minority K–12 students. The Dallas school district is the nation's 12th-largest. It has a 93% minority enrollment and 81% of its students come from low-income households. Yet Dallas students achieve outstanding AP results. African American and Hispanic students pass AP exams in mathematics, science, and English at a rate four times higher than the national average for minority students, and female students pass the exams at twice the national rate.[56]

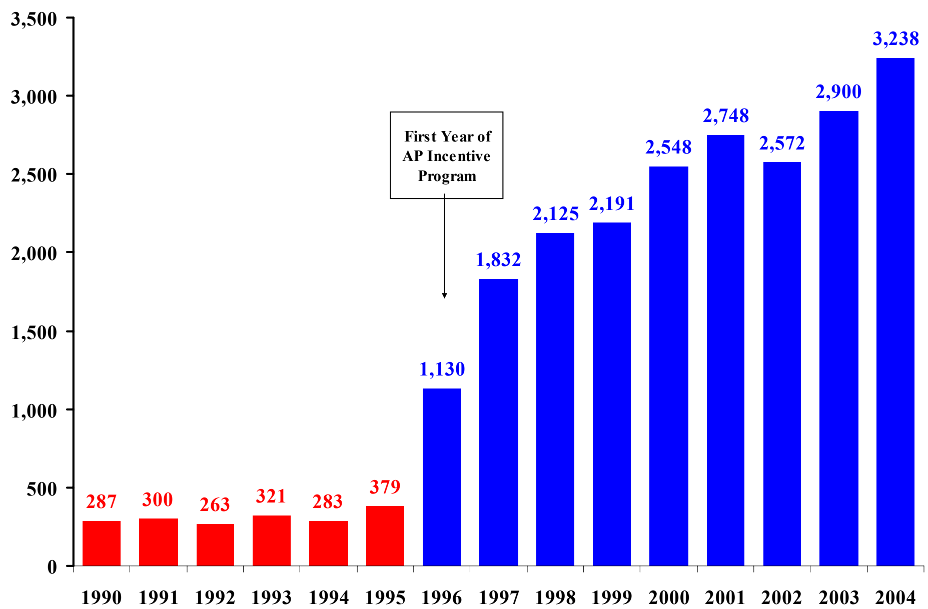

FIGURE 5-3 The number of students taking AP mathematics, science, and English examinations in APIP schools has increased more than 8-fold over 9 years.

SOURCE: College Board, 2004 results based on updated data received from the Dallas Independent School District for AP exams in mathematics, science, and English.

EFFECTIVE CONTINUING PROGRAMS

The committee proposed expansion of two additional approaches to improving K-12 science and mathematics education that are already in use:

- **Statewide Specialty High Schools**. An effective way to increase student achievement in science and mathematics is to provide an intensive learning experience for the best students.[57] These schools immerse students in high-quality science and mathematics education, serve as testing grounds for curricula and materials, provide in-classroom

[56] Passing rate is calculated as number of students passing exam per 1000 Junior and Senior high school students in the Dallas Independent School District compared to all of Texas and all of the United States.
[57] See: Science Education: Hothouse High. *Nature* 435: 874-875.

educational opportunities for K–12 teachers, and have the resources and staff for summer programs to introduce students to science and mathematics. One model among many is the North Carolina School of Science and Mathematics (NCSSM), which opened in 1980. NCSSM enrolls juniors and seniors from most of North Carolina's 100 counties. NCSSM's unique living and learning experience made it the model for 16 similar schools around the world. It is the first school of its kind in the nation—a public, residential high school where students study a specialized science and mathematics curriculum. Such schools are innovative—they train students from all districts—and they provide a laboratory for curricular materials and teacher education. At NCSSM, teachers come for a "sabbatical year," and the school has a structure and the personnel it needs to offer summer institutes for outstanding students.

- **Inquiry-Based Learning.** Summer research programs stimulate student interest and achievement in science, mathematics, and technology. Programs that involve several institutions or public–private partnerships should be encouraged, as should those designed to stimulate low-income and minority student participation.

CONCLUSION

Public education is our country's most valuable asset, yet our system has too long ignored the development of critical teaching and workforce skills.

The committee has examined a number of education programs that have been shown to work, identified core program components—strong content knowledge, practical pedagogical training, ongoing mentoring and education, and incentives—and recommended the programs be implemented as one would a research program: with built-in benchmarks, evaluations, and ongoing education--with the expectation that there is no one program that will fit every situation.

Thorough education in science, mathematics, and technology will start students on the path to high-technology jobs in our knowledge economy. To develop an innovative workforce, we must begin now to change public education in science and mathematics.

Virtually all quality jobs in the global economy will require certain mathematical and scientific skills. The committee's objectives are to assure that all students will gain these necessary skills and have the opportunity to become part of a cadre of world-class scientists and engineers that can create the new products that will in turn broadly enhance the nation's standard of living. In short, our goal in producing highly qualified scientists and engineers is to assure that a broad variety of quality jobs are available to all Americans.

When fully implemented, the committee's recommendations will produce the academic achievement in science and technology that every student should exhibit and afford numerous opportunities for further learning in their fields. Excellent teachers, increasing numbers of students meeting high academic standards, and measurable results will become the academic reality.