Congressional Research Service

Report 98-871

Science, Engineering, and Mathematics Education: Status and Issues

Christine M. Matthews, Resources, Science, and Industry Division

June 27, 2008

Abstract. In this report, selected science and education issues are presented, along with a summary of findings from various studies. The issues discussed include precollege science and mathematics concerns; improving undergraduate and graduate education; demographics and the science and engineering talent pool; foreign science and engineering students; and congressional activity.

Order Code 98-871

CRS Report for Congress

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Prepared for Members and Committees of Congress

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Summary

An important aspect of U.S. efforts to maintain and improve economic competitiveness is the existence of a capable scientific and technological workforce. A major concern of the 110th Congress may be regarding the future ability of the U.S. science and engineering base to generate the technological advances needed to maintain economic growth. Discussions have centered on the quality of science and mathematics education and training and on the scientific knowledge of those students entering other disciplines. Even students pursuing nonscientific and nonmathematical specialities are likely to require basic knowledge of scientific and technological applications for effective participation in the workforce. Charges are being made that many students complete high school scientifically and technologically illiterate.

Precollege science and mathematics instruction has an important relationship to the future supply of U.S. scientific and technological personnel and to the general scientific literacy of the nation. However, several published reports indicate important shortcomings in science and mathematics education and achievement of U.S. students at the precollege level. Some findings in the reports revealed that many science and mathematics teachers do not have a major in the discipline being taught; and that U.S. students, themselves, on international measures, perform less well than their international counterparts.

A September 2006 report on the future of higher education states that while our colleges and universities have much to applaud for in their achievements, there are some areas where reforms are needed. As higher education has evolved, it simultaneously has had to respond to the impact of globalization, rapidly evolving technologies, the changing needs of a knowledge economy, and a population that is increasingly older and more diverse.

In the 21st century, a larger proportion of the U.S. population will be composed of certain minorities — blacks, Hispanics, and Native Americans. As a group, these minorities have traditionally been underrepresented in the science and engineering disciplines compared to their proportion of the total population. A report of the National Science Foundation (NSF) reveals that blacks, Hispanics, and Native Americans as a whole comprise more that 25% of the population and earn, as a whole, 16.2% of the bachelor degrees, 10.7% of the masters degrees, and 5.4% of the doctorate degrees in science and engineering.

On August 9, 2007, President Bush signed into law P.L. 110-69, The America COMPETES Act (H.R. 2272). The legislation is directed at increasing research investment, improving economic competitiveness, developing an innovation infrastructure, and strengthening and expanding science and mathematics programs at all points on the educational pipeline. The America COMPETES Act authorizes $33.6 billion for FY2008 through FY2010 for science, mathematics, engineering, and technology programs across the federal government. This report will be updated as events warrant.

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Science, Engineering, and Mathematics Education: Status and Issues

Background

An important aspect of U.S. efforts to improve economic competitiveness is the existence of a capable scientific and technological workforce. Concern has been expressed about the future ability of the U.S. science and engineering base to generate the technological advances needed to maintain economic growth.[1] Some discussions have centered on the quality of science and mathematics undergraduate education and training. The design and structure of the scientific curriculum are thought to discourage a number of highly qualified students from entering and remaining in the disciplines.[2] Other discussions have focused on the scientific knowledge of those students entering other disciplines. Even students pursuing nonscientific and nonmathematical specialties will require basic knowledge of scientific and technological applications and mathematical reasoning in order to adapt to constant changes in the labor market.[3]

Precollege science and mathematics instruction also has an important relationship to the future supply of U.S. scientific and technical personnel. A basic science and mathematics education is considered necessary not only for those who will enter science as majors, but for all citizens to understand scientific and technical issues that affect their lives. However, several indicators of the performance of U.S. students in science and mathematics education at the precollege level reveal a mixed

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[1] See for example The National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, Committee on Science, Engineering, and Public Policy, Washington, DC, National Academy Press, 2007, 664 pp., RAND Corporation, National Defense Research Institute, Titus Galama and James Hosek, *U.S. Competitiveness in Science and Technology*, June 2008, 155 pp, Noyes, Andrew, "DHS Official Warns U.S. Workforce Faces Skills 'Crisis'," Congress Daily PM, June 16, 2008, [http://www.nationaljournal.com/congressdaily/print_friendly.php?ID=cdp_20080616_9335], and Augustine, Norman R., "Living Off Past Investments," *Education Week*, v. 26, January 7, 2007, p. 28.

[2] National Science Board, *Science and Engineering Indicators 2008*, Volume 1, NSB08-01, Arlington, VA, January 15, 2008, pp. 2-22 - 2-24.

[3] See for example Cavanagh, Sean, "Frustrations Give Rise to New Push for Science Literacy," *Education Week*, v. 27, March 5, 2008, p. 12, The National Academies, *Research on Future Skill Demands: A Workshop Summary*, Division of Behavioral and Social Science and Education, Washington, DC, National Academy Press, 2008, 126 pp., and National Center on Education and the Economy, *Tough Choices or Tough Times, The Report of the New Commission on the Skills of the American Workforce*, Executive Summary, January 2007, 26 pp.

picture of successes and shortcomings.[4] Still other indicators show that the science and mathematics curriculum at the precollege level is unfocused and that many science and mathematics teachers lack a major or minor in the subject area being taught.[5]

Reform efforts at improving precollege science and mathematics education have included the development of recommended national standards. Such standards describe what children should know, when they should know it, and how to assess what they know. These standards emphasize inquiry based education as being the most effective in retaining the interest of all students. While many states and school districts have created new science and mathematics standards that to some degree are drawn from standards of the National Council of Teachers of Mathematics and the National Research Council, adoption and implementation of the standards at the local school level where there is often limited resources and unprepared teachers has proven to be problematic.[6]

The change from a labor-based manufacturing to a knowledge-based manufacturing and service economy demands certain skills of our citizenry.[7] The National Science Foundation (NSF) projects that in the increasingly changing context for science and technology, a workforce trained in the sciences and engineering is necessary for continued economic growth. A May 2007 report of the Department of Education states that:

> There is increasing concern about U.S. economic competitiveness, particularly the future ability of the nation's education institutions to produce citizens literate in STEM concepts and to produce future scientists, engineers, mathematicians, and technologists. Such experts are needed to maintain U.S. preeminence in science, technology, engineering and mathematics. While other countries around the world strive to improve their own education systems and to expand their

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[4] Department of Education, National Center for Education Statistics, *Highlights From the Third International Mathematics and Science Study (TIMSS) 2003*, NCES2005-005, Washington, DC, December 2004, pp. 1-25.

[5] See for example the Department of Education, National Center for Education Statistics, *Qualifications of the Public School Teacher Workforce: Prevalence of Out-of-Field Teaching 1987-88 to 1999-2000*, NCES 2002-603 Revised, Washington, DC, August 2004, 92 pp, and Ingersoll, Richard M., "Out of Field Teaching and the Limits of Teacher Policy," A Research Report Sponsored by the Center for the Study of Teaching and Policy and The Consortium for Policy Research in Education, September 2003, 29 pp.

[6] The National Academies, Division of Behavioral and Social Sciences and Education, Hollweg, Karen S. and David Hill, *What is the Influence of the National Science Education Standards?: Reviewing the Evidence, A Workshop Summary*, Washington, DC, 2003, 208 pp.

[7] Deitz, Richard and James Orr, "A Leaner, More Skilled U. S. Manufacturing Workforce," *Current Issues in Economics and Finance*, v. 12, February/March 2006, 7 pp., and Olson, Lynn, "Economic Trends Fuel Push to Retool Schooling," *Education Week*, v. 25, March 22, 2006, pp. 1, 20, 22, 24, The Task Force on the Future of American Innovation, "*The Knowledge Economy: Is the United States Losing Its Competitive Edge?*," February 16, 2005, 16 pp.

economies, the U.S. will have to work even harder in the coming years to maintain its competitive edge.[8]

In this report, selected science and education issues are presented, along with a summary of findings from various studies. The issues discussed include precollege science and mathematics concerns; improving undergraduate and graduate education; demographics and the science and engineering talent pool; foreign science and engineering students; and congressional activity. For expanded discussion of science and mathematics education issues see CRS Report RL34328, *America COMPETES Act: Programs, Funding, and Selected Issues,* by Deborah D. Stine, and CRS Report RL33434, *Science, Technology, Engineering, and Mathematics (STEM) Education: Background, Federal Policy, and Legislative Action*, by Jeffrey J. Kuenzi. This report will be updated as events warrant.

Precollege Science and Mathematics Concerns

Precollege (K-12) science and mathematics instruction has an important relationship to the future supply of U.S. scientific and technological personnel. The technological demands of the workforce are increasing exponentially. A basic science and mathematics education is necessary not only for those who will enter science as majors, but for all citizens to understand scientific and technical issues that affect their lives. In addition, scientific and technical skills are a requirement for an increasingly wide range of occupations such as health care, banking, insurance, and energy production. Whether individuals are in the service sector, manufacturing, government, or management, many believe that some level of scientific literacy is required.

The term "reform" is repeated throughout discussions of science education at the precollege level, covering such issues as: school curriculum and the quality of science instruction, student interest in science, the shortage of qualified teachers, teacher training and retraining, student achievement on science and mathematics measures, and the participation of minorities and women in science.[9] The U.S. educational system has a long history of attempted education reforms. One particular report that received considerable attention was released in 1983 by the Department of Education (ED). The report, *A Nation At Risk*, attacked the school system, declaring that U.S. schools were sinking under a "rising tide of mediocrity," partly as a result of a shortage of qualified teachers in science, mathematics, and other

[8] Department of Education, *Report of the Academic Competitiveness Council*, Washington, DC, May 2007, p. 5.

[9] See for example Echevarria, Marissa, "Hands on Science Reform, Science Achievement, and the Elusive Goal of 'Science for All' in a Diverse Elementary School District," *Journal of Women and Minorities in Science and Engineering*, v. 9, 2003, pp. 375-402.

essential disciplines.[10] More than 20 years after the report, there is some debate as to whether or not our educational system is still "at risk."[11]

Reforms in science and mathematics education have focused on both what to teach and how to teach it. The 1989 report of the American Association for the Advancement of Science (AAAS), *Project 2061, Science for All Americans,* presented goals for science, mathematics, and technology literacy.[12] The goals presented offered multidisciplinary instructions in the real world, structured so students would use the discovery process to study issues that are multidimensional, to arrive at alternative approaches, and to be able to anticipate both positive and negative consequences of their choices.

In 2000, the National Council of Teachers of Mathematics (NCTM) released a revised *Principles and Standards for School Mathematics,* which described how students should be taught to solve non-routine problems in meaningful context.[13] The NCTM standards promoted the policy of students learning through induction rather than memorization, directing the instructional process on inquiry[14] as opposed to the traditional tell-and-test approach, and promoting assessment methods that are open-ended instead of machine-scoreable. More recently, a 2005 report of the Fordham Institute states that "While state standards are very much in flux, the nation, in its entirety, is neither making progress nor losing ground when it comes to its expectations for what students should learn in science."[15]

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[10] Department of Education, *A Nation At Risk: The Imperative for Education Reform, A Report to the Nation and the Secretary of Education*, Washington, 1983, 65 pp.

[11] See for example Kirsch, Irwin, Henry Braun, Kentaro Yamamoto, and Andrew Sum, *America's Perfect Storm: Three Forces Changing Our Nation's Future*, A report of the Educational Testing Service, Policy Information Center, January 2007, pp. 8-10, Thornburgh, Nathan, "Dropout Nation," *Time*, April 17, 2006, pp. 32-40, Anderson, James, and Dara N. Byrne, "The Unfinished Agenda of Brown v. Board of Education," *Black Issues in Higher Education*, 2004, 222 pp., and "Fifty Years After Brown," *U.S. News & World Report*, March 22, 2004, pp. 64-95.

[12] American Association for the Advancement of Science, *Science for All Americans, A Project 2061 Report on Literacy Goals in Science, Mathematics, and Technology*, Washington, 1989, 217 pp.

[13] National Council of Teachers of Mathematics, Commission on Teaching Standards, *Principles and Standards for School Mathematics*, Reston, VA, July 28, 2000, 402 pp.

[14] "Inquiry is a multifaceted activity that involves looking for patterns; making observations; posing questions; looking for and thinking about relationships; examining other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results." "Inquiry-Based Instruction," [http://www.nyssi.org/nyssi/nyssib.htm].

[15] Gross, Paul R., with Ursula Goodenough, Susan Haack, Lawrence S. Lerner, Martha Schwartz, and Richard Schwartz, Thomas B. Fordham Institute, *The State of Science Standards*, December 2005, p. 19, and Barton, Paul E., Educational Testing Service, Policy Information Report, *Unfinished Business: More Measured Approaches in Standards-Based Reform*, January 2005, 53 pp.

The ongoing discussions of reform in science education stress the importance of inquiry-based instruction as the most beneficial in assisting students to think critically, to work independently or cooperatively, and to solve problems as they encounter them in different and novel situations.[16] In 2002, the National Research Council released its publication, *Investigating the Influence of Standards, A Framework for Research in Mathematics, Science, and Technology Education.*[17] The report examined two primary questions: (1) How has the system responded to the introduction of nationally developed mathematics, science, and technology standards?, and (2) What are the consequences for student learning? The report offered guideposts for determining the influence of nationally developed science, mathematics, and technology standards and evaluates the significance of the influence on student learning, on teachers and pedagogy, and on the education system as a whole.

Teacher Training and Qualifications

Many elementary teachers reportedly admit that they feel uncomfortable teaching science because they lack confidence in their knowledge about science and their understanding of scientific concepts.[18] A 2004 publication of the National Center for Education Statistics reports that in the middle grades for school year 1999-2000, approximately 68.5% of the students in mathematics were being taught by teachers who had no major or certification in the field. For sciences, the proportion being taught by teachers with no major or certification was 57.2% for general science, 64.2% for biology/life science, and 93.2% for physical science.[19] In high

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[16] Cavanagh, Sean, "Science Labs: Beyond Isolationism," *Education Week*, January 10, 2007, Hanauer, David I., Deborah Jacobs-Sera, Marisa L. Pedulla, Steven G. Cresawn, Roger W. Hendrix, and Graham F. Hatfull, "Teaching Scientific Inquiry," *Science*, v. 314, December 22, 2006, pp. 1880-1881, and Teicher, Stacy A., "The Mystery of Teaching Science ... Solved!," *The Christian Science Monitor*, December 1, 2005, p. 13.

[17] National Research Council, Committee on Understanding the Influence of Standards in K-12 Science, Mathematics, and Technology Education, *Investigating the Influence of Standards, A Framework for Research in Mathematics, Science, and Technology Education*, Washington, 2002, 130 pp.

[18] The National Commission on Teaching and Americas Future reports that teachers with the least amount of experience are generally working in urban areas — school districts that have the greatest need for qualified teachers. See also National Research Council, Division of Behavioral and Social Sciences and Education, Singer, Susan R., Margaret L. Hilton, and Heidi A. Schweingruber, *America's Lab Report, Investigations in High School Science*, Washington, DC, 2006, p. 146, Friel, Brian, "A New Sputnik Moment?," *The National Journal*, v. 37, July 30, 2005, pp. 2452-2453, Center for the Study of Teaching and Policy, University of Washington, *Out-of-Field Teaching, Educational Inequality, and the Organization of Schools; An Exploratory Analysis*, January 2002, 32 pp. and King, Ledyard, "Richer Areas More Successful in Attracting Qualified Teachers," *USA Today*, April 24, 2006,[http://www.usatoday.com/news/education/2006-04-24-education_x.htm?POE=NEWISVA].

[19] Those students being taught by teachers with no major, minor, or certification were 21.9% for mathematics, 14.2% in science, 28.8% in biology/life science, and 40.5% in physical science. Department of Education, National Center for Education Statistics, *Qualifications*

(continued...)

school, approximately 31.4% of the students in mathematics, 44.7% in biology/life science, 61.1% in chemistry, and 66.5% in physics are being taught by teachers with no major and certification in the respective field.[20]

Supplemental teacher training can be effective for those teachers who did not have science or mathematics education majors or who took few lecture-based science and mathematics courses in college.[21] Award-winning teachers testifying before the House Science Committee stated that in order for professional development to be effective, teachers need to be provided with proper materials and resources (internal and external to the school), training in the inquiry-based learning process, and class release time.[22] The National Academies report, *Rising Above the Gathering Storm - Energizing and Employing America for a Brighter Economic Future*, calls for the "enhanced education" of teachers at the precollege level by focusing on teacher education and professional development.[23] The report states that:

> 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.[24]

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[19] (...continued)
of the Public School Teacher Workforce: Prevalence of Out-of-Field Teaching 1987-88 to 1999-2000, p. 10.

[20] For high school students, the proportion being taught by teachers with no major, minor, or certification in the field is 8.6% for mathematics, 9.7% for biology/life science, 9.4% for chemistry, and 17% for physics. A report of the Educational Testing Service found that for both science and mathematics, students whose teachers majored or minored in the subject being taught outperformed their classmates by approximately 39% of a grade level. Educational Testing Service, Wenglinsky, Harold, *How Teaching Matters: Bringing the Classroom Back Into Discussions of Teacher Quality*, October 2000, p. 26.

[21] See Committee for Economic Development, Research and Policy Committee, *Learning for the Future - Changing the Culture of Math and Science Education to Ensure a Competitive Workforce*, May 7, 2003, pp.36-40, and National Science Board, Committee on Education and Human Resources, *The Science and Engineering Workforce - Realizing America's Potential*, NSB 03-69, August 14, 2003, pp. 31-35.

[22] House Committee on Science, *The 2004 Presidential Awardees for Excellence in Mathematics and Science Teaching: A Lesson Plan for Success*, Testimonies from the 2004 Presidential Awardees for Excellence in Mathematics and Science Teaching, 109th Cong., 1st Sess., April 14, 2005, [http://www.house.gov/science/press/109/109-51.htm]. See also Stanley, Marshall J., "A Veteran's View of Science Education Today," *The Review of Policy Research*, v. 20, December 22, 2003, p. 629.

[23] The National Academies, *Rising Above the Gathering Storm - Energizing and Employing America for a Brighter Economic Future*, pp.112-135.

[24] Ibid., p. 119.

Student Achievement

Various assessments and reports have documented the progress of U.S. students and their participation in science and mathematics. In October 2005, the National Assessment Governing Board[25] released the results of the National Assessment of Educational Progress (NAEP) 2005 mathematics assessment for grades 4 and 8.[26] The NAEP 2005 mathematics assessment was based on a framework that was developed through a comprehensive national consultative process. The results are reported according to three basic achievement levels — basic, proficient, and advanced.[27] The proportion of students performing at the basic and proficient levels increased for 4th and 8th grade students from 2003 to 2005. Higher percentages of black and Hispanic students, at both grade levels, scored at or above basic and proficient in 2005 than in any previous assessment. The score gap between white students and black and Hispanic students continue, but the gap has narrowed.

In May 2005, the NAEP's 2005 science assessments were released.[28] The NAEP 2005 science assessment is to provide a baseline for science achievement and to assist in determining the progress being made toward the fifth National Goal. Similar to the mathematics assessments, results are reported at three achievement levels. Data revealed that the average scores of 4th graders rose approximately 4 points in comparison with 1996 and 2000. For 8th grade students, there was no significant change in overall scores in 2005 from the previous assessments.[29] For 12th graders, there was no change in performance from the administration in 2000. However, in 2005, 12th graders received lower average scores than in 1996. At this grade level, the percentage of students performing at or above the basic level, at or above the proficient level, and at the advanced level all declined since 1996. In addition, the number of students who scored below basic increased since 1996.

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[25] The National Assessment Governing Board is a bipartisan 26-member Board authorized by Congress to make policy for the NAEP and to measure the academic achievement of students in selected grades at the precollege level. The Board is authorized to establish performance levels in the areas of science, mathematics, reading, U.S. history, geography, and other subjects.

[26] Department of Education, Office of Education Research and Improvement, *The Nation's Report Card: Mathematics 2005*, NCES2006-453, Washington, DC, October, 2005, 49 pp. The 2005 assessment included nationally representative samples of approximately 172,000 4th graders and 162,000 8th graders. The racial/ethnic groups are black, white, Hispanic, Native Americans/Alaskan Natives, and Asian/Pacific Islanders.

[27] The basic level represents partial mastery of prerequisite knowledge and skills, the proficient level represents solid academic performance, and the advanced level denotes superior performance. These achievement levels, however, are developmental and remain in transition.

[28] Department of Education, Office of Education Research and Improvement, *The Nation's Report Card: Science 2005*, NCES 2006-466, Washington, DC, May 24, 2006, 42 pp. The assessment was administered to a representative sample of 304,800 students in grades 4, 8, and 12.

[29] Black students showed the only score increase among all racial/ethnic groups at grade 8.

Several reports on the state of precollege education, especially international comparisons, have revealed that U.S. students do not perform at the level of their international counterparts. The Trends in International Mathematics and Science Study (TIMSS) for grades 4 and 8, conducted in 2003, investigated mathematics and science curricula, instructional practices, and achievement in 46 countries (at either the 4th or 8th grade level or both).[30] Results at grade 4 showed that in mathematics, U.S. students scored above the international average. U.S. students performed lower than their peers in 11 of the other 24 participating countries and out performed their peers in 13 of the countries. Singapore was the top performing jurisdiction in mathematics at the 4th grade level, followed by Hong Kong, Japan, Chinese Taipei, and Belgium-Flemish. At the 8th grade level, the average score for U.S. students exceeded those of their peers in 25 of the 44 other participating countries. U.S. 8th grade students were out performed by students in nine jurisdictions, including Singapore, Republic of Korea, Hong Kong SAR,[31] Chinese Taipei, and Japan.[32]

The results for TIMSS in science revealed that at the 4th grade level, U.S. students outperformed 16 of the other 24 participating countries. U.S. students, with a higher average score than the international average, performed less well than Singapore, Chinese Taipei, Japan, Hong Kong SAR, and England. At the 8th grade level, U.S. students again received a higher average score than the international average and outperformed their peers in 36 of the other 44 participating countries in the subset of measures. U.S. students ranked 9th, scoring below that of Singapore, Chinese Taipei, Republic of Korea, Hong Kong, Estonia, Japan, Hungary, and the Netherlands.[33]

Some in the education community have charged that international comparisons are statistically invalid because of widely disparate culture, diversity in school systems, and significant differences in curriculum. However, there is the counter argument that due to refinement in collection of data and methodological procedures employed in the analyses, the comparisons are valid for the student populations examined. ED estimates that the United States spends approximately $455 billion annually for elementary and secondary education.[34] What is puzzling to some is with

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[30] Department of Education, National Center for Education Statistics, *Highlights From the Trends in International Mathematics and Science Study (TIMSS) 2003*, NCES 2005-005, Washington, DC, December 2004, 107 pp. TIMSS data have been collected in 1995, 1996, 2003, and 2007. TIMSS 2007 findings will be released in December 2008.

[31] Hong Kong is a Special Administrative Region (SAR) of the People's Republic of China.

[32] Ibid., p. 5

[33] Students from Singapore consistently ranked at the top in both mathematics and science at both grade levels. For expanded discussion of international trends see for example Department of Education, National Center for Education Statistics, *Comparing Science Content in the National Assessment of Education Progress (NAEP) 2000 and Trends in International Mathematics and Science Study (TIMSS) 2003 Assessments*, Technical Report, NCES 2006-026, Washington, DC, March 2006, 70 pp.

[34] Department of Education, National Center for Education Statistics, *Revenues and Expenditures for Public Elementary and Secondary Education: School Year 2002-2003*, (continued...)

that level of funding, how can the U.S. system of education with graduate schools considered to be the best in the world, a system that produces some of the best scientists and engineers, also produce some students in elementary and secondary schools who perform less well on international measures? How can the performance of U.S. students on the TIMSS be explained when some groups of students showed no measurable difference from the previous assessment, and some even a measurable decline?

Improving Undergraduate and Graduate Education

Undergraduate Education

While the uncertain job market for some scientists and engineers may have an effect on the enrollments in science and engineering, the U.S. system of higher education is called upon to continue to produce the qualified scientific and technical personnel necessary to maintain an intellectual and economic leadership.[35] Colleges and universities are facing the mounting task of better educating their undergraduate and graduate students by restructuring their curricula to increase the versatility and employability of the graduates. All disciplines have been targets, however, considerable importance is placed on graduates in the natural sciences, engineering, health sciences, computer sciences, and other quantitatively-based fields.

One challenge facing research institutions is that of finding a balance between the basic academic activities of teaching and research. Within the scientific and engineering disciplines, attempting to find the flexibility to blend the priorities of teaching and research has been a perennial problem. The standing of an institution is in direct relationship to the research productivity of its faculty, and the competition for grants and scholars has led many research institutions to place increased emphasis on research at the expense of teaching. In many research institutions, research productivity has been given more weight than teaching effectiveness when deciding tenure or promotion. Efforts are underway at some institutions to change the reward system and evaluation of their faculty members.[36]

An additional challenge for research universities is the need to address the complaints concerning undergraduate teaching. Many of these complaints are

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[34] (...continued)
NCES 2005-353R, Washington, DC, October 2005, p. 1.

[35] See for example Jackson, Shirley Ann, President, Rensselaer Polytechnic Institute, "Intellectual Security and the Quiet Crisis," November 29, 2005, 7 pp., Freeman, Richard B., National Bureau of Economic Research, "Does Globalization of the Scientific/Engineering Workforce Threaten U. S. Economic Leadership?," Working Paper 11457, June 2005, 45 pp, [http://www.nber.org/papers/w11457], and National Science Board, *An Emerging and Critical Problem of the Science and Engineering Labor Force,* NSB04-07, Arlington, VA, January 2004, pp. 1-4.

[36] O'Meara, KerryAnn, R. Eugene Rice, and Russell Edgerton, *Faculty Priorities Reconsidered: Rewarding Multiple Forms of Scholarship*, August 2005, 368 pp.

focused on the use of graduate students as teaching assistants in the undergraduate programs, especially in the science and engineering disciplines. A considerable number of undergraduate courses in science and engineering are taught by foreign graduate students who do not have a good command of the English language. *Reinventing Undergraduate Education* found that "... [T]he classroom results of employing teaching assistants who speak English poorly, as a second language, and who are new to the American system of education constitute one of the conspicuous problems of undergraduate education."[37]

In 2003, the National Research Council released the report, *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics.*[38] The report noted that colleges and universities are being held far more accountable for the education of their students than in the past. Institutions with peer review mechanisms to evaluate faculty research in science, mathematics, and engineering, should have the same of attention directed at evaluating the faculty teaching in those disciplines. The public and private sectors that make significant investments in university research suggested that faculty members excelling in the classroom should be recognized and rewarded similar to those faculty engaged in research.

The report recommended strategies for evaluating undergraduate teaching and learning in science, mathematics, engineering, and technology. The methods used for evaluation could serve as a basis for the professional advancement of faculty. Faculty are encouraged to set definitive goals for their students and then determine if the goals are being met. In addition to the faculty, recommendations for evaluating teaching and learning were made for presidents, boards, and academic officers; deans, department chairs and peer evaluators; and for research sponsors and granting and accrediting agencies. The recommendations were based on the following tenets:

- Effective postsecondary teaching in science, mathematics, and technology should be available to *all* students, regardless of their major.
- The design of curricula and the evaluation of teaching and learning should be collective responsibilities of faculty in individual departments or, wherever appropriate, through interdepartmental arrangements.
- Scholarly activities that focus on improving teaching and learning should be recognized as bona fide endeavors that are equivalent to other scholarly pursuits. Scholarship devoted to improving teaching effectiveness and learning should be accorded the same

[37] Ibid., p. 7.

[38] National Research Council, Committee on Recognizing, Evaluating, Rewarding, and Developing Excellence in Teaching of Undergraduate Science, Mathematics, Engineering, and Technology, *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics,* Editors, Fox, Marye Anne and Norman Hackerman, Washington, DC, 2003, 215 pp.

> administrative and collegial support that is available for efforts to improve other research and service endeavors.[39]

On March 15, 2006, the House Science Committee held a hearing to explore the efforts of colleges and universities in improving their scientific and engineering programs.[40] The Committee was interested also in what role the federal government could play in encouraging more students to enter the science, mathematics, and engineering disciplines. Witnesses testified about the factors that shape the quality of undergraduate reforms in the scientific and engineering disciplines. Elaine Seymour, University of Colorado, contends that there is a decline in the perceived value of teaching. Teaching as a career is believed by many undergraduates as being of low status, pay, and prospects. Also, faculty in many institutions are more focused on research than teaching. Academic success is measured by grant writing and publications. In many science and engineering departments, a portion of faculty salary is from research grants. As a result, there is less interactive teaching by many faculty and more "straight lecturing." Many classes become the responsibility of teaching assistants. In numerous surveys, students have indicated that "poor teaching" and "unsatisfactory learning experiences" were the primary reasons for switching majors and leaving the sciences. Seymour states that the institutional reward system and the pressure to obtain grants have consequences for both undergraduate and K-12 education in the science, mathematics, and engineering.

John Burris, President, Beloit College, testifying before the March 15 hearing, offered several recommendations as to how the federal government can identify, assess, and disseminate that which works in undergraduate science, mathematics, and engineering programs. He suggested that with the proposed doubling of the NSF budget over the next ten years,[41]there should be a doubling of the funding targeted specifically for strengthening and sustaining undergraduate programs in colleges and universities. Burris stated that "Significant parts of what works are: I) attention to how students learn; ii) an institutional culture that has a common vision about the value of building research-rich learning environments; and iii) faculty who are eager to remain engaged within their disciplinary community, and who have the resources of time and instrumentation to do so."[42] He suggested that the increased funding be directed at networks, collaborations, and partnerships. He further called for the establishment of a taskforce to oversee the proposed doubling of undergraduate funds. The task force would be charged with outlining NSF undergraduate priorities

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[39] Ibid., p.2.

[40] House Committee on Science, Subcommittee on Research, *Undergraduate Science, Math and Engineering Education: What's Working?,* 109th Cong., 2nd Sess., March 15, 2006, [http://www.house.gov/science/hearings/research06/march%2015/index.htm].

[41] The American Competitiveness Initiative (President Bush, February 2006), and several pieces of legislation have, among other things, proposed the doubling of NSF research and related activities budget over 5 to 10 years.

[42] Ibid., Written testimony of John Burris, President, Beloit College, p. 5.

that are contained in the numerous reports calling for the federal government to strengthen and reenergize investments in science and engineering education.[43]

A September 2006 report on the future of higher education states that while our colleges and universities have much to applaud for in their achievements, there are areas where improvements are needed.[44] As higher education has evolved, it simultaneously has had to respond to the impact of globalization, rapidly evolving technologies, the changing needs of a knowledge economy, and an increasingly diverse and aging population.[45] The report notes that:

> The United States must ensure the capacity of its universities to achieve global leadership in key strategic areas such as science, engineering, medicine, and other knowledge-intensive professions. We recommend increased federal investment in areas critical to our nation's global competitiveness and a renewed commitment to attract the best and brightest minds across the nation and around the world to lead the next wave of American innovation.[46]

Graduate Education

Graduate education in science and mathematics has been the subject of several reports and committees. In the fall of 1993, the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint committee of the NAS, the National Academy of Engineering, and the Institute of Medicine (IOM), proposed a comprehensive study on the status of the graduate education and research training being offered in U.S. colleges and universities. The committee's actions led to the release of the 1995 report, *Reshaping the Graduate Education of Scientists and Engineers.* The report stated:

> The three areas of primary employment for PhD scientists and engineers — universities and colleges, industry, and government — are experiencing simultaneous change. The total effect is likely to be vastly more consequential for the employment of scientists and engineers than any previous period of

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[43] See for example Business Roundtable, Brush, Silla, "Fixing Undergraduate Education," *U. S. News & World Report*, March 6, 2006, p. 28, *Tapping America's Potential - The Education for Innovation Initiative*, Washington, DC, July 2005, 18 pp., the Business-Higher Education Forum, *A Commitment to America's Future: Responding to the Crisis in Mathematics and Science Education*, January 2005, 40 pp., Association of American Universities, *National Defense Education and Innovation Initiative, Meeting America's Economic and Security Challenges in the 21st Century*, Washington, DC, January 2006, 24 pp., and National Science Board, *America's Pressing Challenge-Building A Stronger Foundation*, NSB06-02, Arlington, VA, January 2006, 6 pp.

[44] *A Test of Leadership — Charting the Future of U.S. Higher Education*, A Report of the Commission Appointed by Secretary of Education, Margaret Spellings, September 2006, 51 pp.

[45] Ibid., p. ix. The "typical" undergraduate student is no longer 18- to 22-years old. Data reveal that of the approximately 14 million undergraduates, more than four in ten are enrolled in community colleges, 33% are over the age of 24, and 40% are attending classes on a part-time basis. Ibid., p. viii.

[46] Ibid., p. 26

> transition has been.... A broader concern is that we have not, as a nation, paid adequate attention to the function of the graduate schools in meeting the country's varied needs for scientists and engineers. There is no clear human-resources policy for advanced scientists and engineers, so their education is largely a byproduct of policies that support research. The simplifying assumption has apparently been that the primary mission of graduate programs is to produce the next generation of academic researchers. In view of the broad range of ways in which scientists and engineers contribute to national needs, it is time to review how they are educated to do so."[47]

COSEPUP had solicited responses concerning the existing structure of graduate education from such groups as: postdoctoral researchers, professors, university officials, industry scientists and executives, representatives of scientific societies, and graduate students themselves. The general sentiment was that while the basic structure of graduate education was sound, some change was warranted in order to respond to "changing national policies and industrial needs."[48]

Some respondents, both inside and outside of academia, indicated that selected doctorate degree programs are too analytical and too oriented toward subspecialities. Survey responses indicated that doctoral students should be provided with a broader training that would allow them to experiment with alternative career paths.[49] Many of the responses from industry and international corporations stated that the nature of industrial work is changing and that the education and training offered by many of the doctoral programs should be changed as well. Industry wants graduate students who will better meet their research and development (R&D) needs and compete effectively with their counterparts worldwide in a rapidly evolving competitive market.[50]

COSEPUP presented a national strategy that was intended to emphasize both versatility and information. One recommendation in the report was that graduate programs should provide a wider variety of career options for their students. This could be accomplished in a program that has a student grounded in the fundamentals of one field that is enhanced by a breadth of knowledge in a related field. Added to such a program would be off-campus experiences exposing the student to the skills requested by an increasing number of employers: the ability to communicate complex ideas, and the experiences of working in groups of interdependent workers. Another recommendation offered to foster versatility in graduate programs was to have those

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[47] The National Academies, *Reshaping the Graduate Education of Scientists and Engineers*, Committee on Science, Engineering, and Public Policy, Washington, DC, 1995, p. 3.

[48] Ibid., p. 40.

[49] See Metheny, Bradie, "Science Training Must Embrace Teamwork, Collaboration, Preparation for Work Outside Academia," *The Washington Fax*, May 13, 2003, Smallwood, Scott, "Graduate Studies in Science Expand Beyond the Ph.D.," *The Chronicle of Higher Education*, v. 47, p. A14, and Potter Wickware, "Postdocs Reject Academic Research," *Nature*, v. 407, September 21, 2000, pp. 429-430.

[50] See *Organizing for Research and Development in the 21st Century - An Integrated Perspective of Academic, Industrial, and Government Researchers,* Sponsored by the National Science Foundation and the Department of Energy, 40 pp.

entities providing financial assistance to graduate students adjust their support mechanisms to include new education and training grants. Research assistantships (RAs), which are a major form of federal assistance to graduate students, are not structured to enhance the versatility of graduate students. (RAs are administered by a faculty member who receives the grant for a specific research topic.) Some observers suggest that the new education and training grants could be patterned after training grants that currently are awarded in the National Institutes of Health and that have been used to establish interdisciplinary programs to encourage graduate students to pursue research in emerging fields.

In the February 1998, the National Science Board (NSB) released a policy paper — *The Federal Role in Science and Engineering Graduate and Postdoctoral Education*.[51] Some of the many issues examined by the NSB were: (1) the relative merits of fellowships and traineeships; (2) the role of graduate students as teachers; (3) the mentoring of graduate students; (4) access to faculty and time to degree; (5) and the continuing underrepresentation of minorities and women in many areas of graduate science and engineering programs. The NSB identified several areas of concern in the federal/university partnership where adjustments "may enhance the capacity of the enterprise to serve the national interest in a changing global environment."[52] The NSB noted that because of changes over the past 50 years, such as increased demand for higher education, the need to respond to advances in communications and information technology, rising tuitions and administrative burdens, and stresses on universities and faculty, require changes and improvement in the federal/university partnership.

One of the stresses confronted by university partnerships, as discussed by the report, is the unintended consequences of federal policies. The increased federal investment in research and education has come with increased oversight and accountability of funding. The report states that

> The growing Federal focus on accountability tends to emphasize short-term research "products" and to de-emphasize benefits to graduate education from engaging in research at the frontiers of knowledge. Increased emphasis on accountability also may result in an increase in the perceived value of postdoctoral researchers compared with graduate students on research grants, thus reducing options for cutting-edge research experience during graduate training.[53]

The recommendations posed by the NSB placed increased emphasis on the expansion of the partnership to include a wider range of colleges and universities, the integration of research and education, increased flexibility of job opportunities outside of academia, and diversity in graduate education. It recommended that the

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[51] The National Science Board, *The Federal Role in Science and Engineering Graduate and Postdoctoral Education*, Contribution to the Government/University Partnership, NSF97-235, Arlington, VA, Approved February 27, 1998, [http://www.nsf.gov/nsb/documents/1997/nsb97235/nsb97235.htm].

[52] Ibid., p. 6.

[53] Ibid.

federal government promote closer collaboration between research and non-research institutions, and to provide greater exposure to both faculty and students to research experiences and opportunities. To address the concern of the narrowness of graduate education, the report suggested that, in addition to the core training, the student should be provided with additional training options that might include interdisciplinary emphasis, teamwork, business management skills, and information technologies. The NSB proposed to reward institutions that established model programs for the integration of research and education.

While recognizing the creation of federal and institutional programs to increase the number of racial and ethnic minorities in the science and engineering disciplines, the NSB noted their participation rate remains of some concern. The report recommended that federal/university partnerships develop more effective mechanisms of increasing diversity in graduate education and to guard "against strategies that inadvertently keep underrepresented groups from the mainstream of research and graduate education."[54]

A 2005 report of the Woodrow Wilson National Fellowship Foundation, *The Responsive Ph.D., Innovations in U.S. Doctoral Education*, analyzed the findings of several studies on doctoral education and detailed the most effective practices from leading doctoral institutions.[55] One of the challenges discussed in the report is the need to combine traditional research with "adventurous" scholarship within and across disciplines. Effective, inclusive, and more relevant training of the doctoral student requires extending knowledge beyond the walls of the institution and the major discipline. Also, the report contends that graduate schools require a significantly stronger central administration and structure that currently exists. A graduate school should guard against operating in isolation within an institution, and instead, create a graduate community of "intellectual cohesiveness" across disciplines. A theme contained in all the reports reviewed was that for reasons of equity and efficacy, there is a need to broaden and reinvigorate efforts to increase the participation of underrepresented minority groups in the sciences. Some recommendations for action offered by the report include:

- The central notion of a graduate school requires strengthening so that it can become a vital force in breaking down barriers between programs and sponsoring a more cosmopolitan intellectual experience for doctoral students.
- Doctoral students need both departmental and extra-departmental structures to give their concerns a strong and effective voice and to cultivate graduate student leadership as a component of graduate education and professional development.

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[54] Ibid., p. 5. See also "Professional MS Offer Promise of More Minorities Pursuing Graduate Studies," *The Washington Fax*, October 10, 2003, and "Postdoc Mentoring In Need of Institutional Changes, National Academies' Convocation Agrees," *Washington Fax*, April 19, 2004.

[55] The Woodrow Wilson National Fellowship Foundation, *The Responsive Ph.D., Innovations in U.S. Doctoral Education*, September 2005, 76 pp. Responses and participation from 20 graduate schools contributed to the report.

- Information about doctoral education, program expectations, and career prospects must be more transparent to students from the moment they begin to consider a Ph.D.
- Doctoral programs urgently need to expand their approaches to mentoring, such as through team mentoring, particularly for attracting and retaining a diverse cohort of students.[56]

Demographics and the Science and Engineering Talent Pool

In the 21st century, global competition and rapid advances in science and technology will require a workforce that is increasingly more scientifically and technically proficient.[57] The Bureau of Labor Statistics reports that science and engineering occupations are projected to grow by 21.4% from 2004 to 2014, compared to a growth of 13% in all occupations during the same time period.[58] It is anticipated that approximately 65% of the growth in science and engineering occupations will be in the computer-related occupations.[59] Faster than average growth is expected in the life sciences, social sciences, and the science and engineering-related occupations of science manager.[60] In testimony before the House Science Committee, Daniel L. Goroff, Vice President for Academic Affairs, Dean of Faculty, Harvey Mudd College, stated that:

> With less than 6% of the world's population, the United States cannot expect to dominate science and technology in the future as it did during the second half of the last century when we enjoyed a massively disproportionate share of the world's STEM [science, technology, engineering, and mathematics] resources. We must invest more the resources we do have, encourage those resources to produce economically useful innovations, and organize the STEM enterprise by

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[56] Ibid., p. 25. Approximately 10 major research institutions have agreed to cooperate in the testing of the recommendations proffered in this report. See also Smallwood, Scott, "Graduate Schools Are Urged to Look Outward to Help Society," *The Chronicle of Higher Education*, v. 52, October 21, 2005, p. A12.

[57] For expanded discussion of the scientific workforce see CRS Report RL34539, *The U.S. Science and Technology Workforce*, by Deborah D. Stine and Christine M. Matthews.

[58] Department of Labor, Bureau of Labor Statistics, Office of Occupational Statistics and Employment Projections, *BLS Releases 2004-2014 Employment Projections*, December 7, 2005, [http://www.bls.gov/news.release/ecopro.nr0.htm].

[59] Computer-related occupations include mathematical science occupations.

[60] NSF acknowledges that predicting the demand for science and engineers in specific areas is difficult. The NSF states that: "Many spending decisions on R&D by corporations and governments are difficult or impossible to anticipate. In addition, R&D money increasingly crosses borders in search of the best place to have particular research performed.... Finally, it may be difficult to anticipate new products and industries that may be created via the innovation processes that are most closely associated with scientists and engineers." National Science Board, *Science and Engineering Indicators, 2008*, Volume 1, p. 3-12.

> working with diverse groups to make sure that innovations developed here or overseas produce prosperity and progress for all.[61]

There are few in the scientific community who argue about the effect of national demographics on the future science and engineering workforce.[62] With the beginning of the 21st century, a larger proportion of the U.S. population will be composed of minorities — blacks, Hispanics, and Native Americans, with the fastest growing minority group being Hispanics.[63] As a group, these minorities traditionally have been underrepresented in the science and engineering disciplines compared to their fraction of the total population.[64] These minorities take fewer high-level science and mathematics courses in high school; earn fewer undergraduate and graduate degrees in science and engineering; and are less likely to be employed in science and engineering positions than white males.[65] Data compiled by the NSF reveal that blacks, Hispanics, and Native Americans/Alaskan Natives as a whole comprise more than 25% of the population and earn, as a whole, 16.2% of the bachelor degrees,

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[61] House Science Committee, *Undergraduate Science, Math, and Engineering Education: What's Working*, Written testimony of Daniel L. Goroff, Vice President for Academic Affairs and Dean of Faculty, Harvey Mudd College, p.6.

[62] The current scientific and engineering workforce is aging. The NSF reports that the number reaching retirement age will increase dramatically over the next two decades. National Science Board, *Science and Engineering Indicators 2008,* Volume 1, pp. 3-45 - 3-46. See also National Science Foundation, *Women, Minorities, and Persons with Disabilities in Science and Engineering October 2007 Update*, Arlington, VA, October 2007, [http://www.nsf.gov/statistics/wmpd/], National Science Board, *Science and Engineering Indicators 2008,* Volume 1, NSB 08-01A, Arlington, VA, January 2008, pp. 3.27-29, *Rising Above the Gathering Storm*, p. 7-4., ,and Jackson, Shirley Ann, President, Rensselaer Polytechnic Institute, "Science and Society: A Nexus of Opportunity," Speech presented on January 17, 2007.

[63] See for example Ashburn, Elyse, "New Data Predict Major Shifts in Student Population, Requiring Colleges to Change Strategies," *The Chronicle of Higher Education*, March 20, 2008, and Schmidt, Peter, "Higher Education Is in Flux as Demographics Change, Federal Report Shows," *The Chronicle of Higher Education*, v. 54, June 6, 2008, p. A23.

[64] See for example Bridges, Brian K., "Bottlenecks and Bulges: The Minority Academic Pipeline," Presentation at the 2nd Annual Conference on Understanding Interventions that Encourage Minorities to Pursue Research Careers, American Council on Education, May 2008, The College Board, *4th Annual Advanced Placement Report to the Nation*, February 13, 2008, 57 pp, National Science Board, *Science and Engineering Indicators 2008,* Volume 1, pp. 1-7 - 1-23, and 3-26 - 3-29, and National Center for Education Statistics, *Status and Trends in the Education of Racial and Ethnic Minorities*, September 2007, 157 pp. Asian Americans are excluded because they are not statistically underrepresented in science, mathematics, engineering, and technology.

[65] White, Jeffrey L., James W. Altschuld, and Yi-Fang Lee, "Persistence of Interest in Science, Technology, Engineering, and Mathematics: A Minority Retention Study," Journal of Women and Minorities in Science and Engineering, v. 12, 2006, pp. 47-64, Landis, Raymond B. California State University, Los Angeles, "Retention by Design - Achieving Excellence in Minority Engineering Education," October 2005, [http://www.nacme.org/pdf/RetentionByDesign.pdf], and National Science Foundation, *Women, Minorities, and Persons with Disabilities in Science and Engineering*, Arlington, VA, May 2008 Update, [http://www.nsf.gov/statistics/wmpd/pdf/may2008updates.pdf].

10.7% of the masters degrees, and 5.4% of the doctorate degrees in science and engineering.[66]

NSF data show that between 2002 and 2005, all racial/ethnic groups, except for whites, either increased their share of earned bachelor and degrees in science and engineering or remained level. Blacks were awarded 8.4% of the bachelors degrees in both 2002 and in 2005. Hispanics increased their share of earned degrees from 7.2% in 2002 to 7.6% in 2005. While Native Americans/Alaskan Natives increased their proportion, it remained at less than 1.0%. Asian/Pacific Islanders proportion of bachelors' degrees increased from 9.0% in 2002 to 9.2% in 2005. For foreign students,[67] the proportion was 3.9% in 2002 and 4.0% in 2005. The decrease in earned bachelors degrees by whites was from 66.5% in 2002 to 64.6% in 2005.[68]

At the master's level, blacks were awarded 6.3% of the degrees in science and engineering in 2005, up from the 6.2% in 2002. The proportion of master's degrees received by Hispanics increased from 4.1% in 2002 to 4.5% in 2005. Asian/Pacific Islanders comprised approximately 6.9% of the masters degrees awarded in 2002 and 7.4% in 2005. For foreign students, the increase was from 27.8% in 2002 to 27.9% in 2005. Native Americans' proportion remained at less than 1.0% between 2002 and 2005. Again, whites reported a decrease in their proportion of earned degrees, dropping from 48.8% in 2002 to 46.7% in 2005.[69]

An analysis of the data for earned degrees at the doctoral level revealed that blacks registered a decrease at this level, from 2.7% of the awards in 2002 to 2.5% in 2005. The degrees earned by Hispanics remained level, 2.6% in 2002 and 2005. As at the other two degree levels, Native Americans' proportion remained at less than 1%. Asian/Pacific Islanders reported a decrease in earned degrees, from 4.3% in 2002 to 4.2% in 2005. Whites also reported a decrease in earned degrees, from 47.4% in 2002 to 42.9% in 2005. Doctoral degrees awarded to foreign students increased from 30.6% in 2002 to 36.3% in 2005.[70]

While minorities have increased their share of degrees awarded in the sciences, poor preparation in science and mathematics is said to be a major factor limiting the appeal of science and engineering to even larger numbers of these groups.[71] A large

[66] National Science Board, *Science and Engineering Indicators*, Volume 2, Appendix Tables 2-27, 2-29, and 2-31.

[67] Foreign students on temporary resident status.

[68] National Science Foundation, *Women, Minorities, and Persons with Disabilities in Science and Engineering,* May 2008 Update, Table C-6.

[69] Ibid., Table E-3.

[70] National Science Board, *Science and Engineering Indicators*, Volume 2, Appendix Table 2-32.

[71] White, Jeffrey L., James W. Altschuld, and Yi-Fang Lee, "Persistence of Interest in Science, Technology, Engineering, and Mathematics: A Minority Retention Study," *Journal of Women and Minorities in Science and Engineering*, v. 12, 2006, pp. 47-64, Landis, Raymond B., California State University, Los Angeles, "Retention by Design - Achieving

(continued...)

number of blacks, Hispanics, and Native Americans lack access to many of the more rigorous college preparatory courses.[72] Enrollment in college preparatory track or courses offers a student a better chance at being accepted at a college through her/his performance on the Scholastic Aptitude Test (SAT) or American College Testing (ACT), and a better chance at success in college.[73] Despite gains in the past 10 years, the average scores made by blacks, Hispanics, and Native Americans, who take both the SAT and the ACT continue to fall behind the average scores of whites and Asian students who take the test.[74]

In addition to recruitment as a problem for greater minority participation in science and engineering, retention of minorities in the educational pipeline, once recruited, also is of concern.[75] (Attrition rates for blacks, Hispanics, and Native Americans are higher than for whites or Asians). Currently, these underrepresented minority groups are reporting increased enrollments in colleges and universities and in their share of science and engineering degrees.[76] However, there is concern that

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[71] (...continued)
Excellence in Minority Engineering Education," October 2005, 27 pp., and National Science Foundation, *Women, Minorities, and Persons with Disabilities in Science and Engineering,* May 2008 Update.

[72] There has been an increase in the number of first-generation minority students enrolling in institutions of higher education. Some of these students are found to be underprepared, and as a result, struggle academically. Institutions have developed initiatives to improve the retention of these students. Horwedel, Dina M., "Putting First-Generation Students First," Diverse Issues in Higher Education, v. 25, April 17, 2008, pp.10-12.

[73] Students who take the more rigorous high school science and mathematics courses are more likely to continue their education than those who do not. The results of the National Educational Longitudinal Study found that 83% of students who took algebra I and geometry, and approximately 89% of students who took chemistry went to college as compared to 36% who did not take algebra and geometry and 43% who did not take chemistry. In general, approximately 51% of high school seniors planning to attend college did not take four years or more of science, and 31% planning to attend college did not take four years or more of mathematics. Students who do take four years of science and mathematics while in high school have been found to improve their SAT score by 100 points.

[74] See for example "There is Good News and Bad News in Black Participation in Advanced Placement Programs," *The Journal of Blacks in Higher Education*, Winter 2005/2006, pp. 98-101, and Lam, Paul C., Dennis Doverspike, Julie Zhao, and P. Ruby Mawasha, "The ACT and High School GPA as Predictors of Success in a Minority Engineering Program," *Journal of Women and Minorities in Science and Engineering*, v. 11, 2005, pp. 247-255.

[75] Wyer, Mary, "Intending to Stay: Images of Scientists, Attitudes Toward Women and Gender as Influences on Persistence Among Science and Engineering Majors," *The Journal of Blacks in Higher Education*, v. 9, 2003, pp.1-16. Persistence data are sometimes spurious in that many minority students do not necessarily drop out, but "stop out" for a period of time and sometimes enroll at other institutions. In addition, persistence data do not always show the effects of part-time attendance and transfer students.

[76] American Council on Education, Office of Minorities in Higher Education, *Minorities in Higher Education Twenty-Second Annual Status Report, 2007 Supplement*, Washington, DC, February 2007, pp. 15-29. The report finds that between 1994 and 2004, minority (continued...)

some of the programs in the universities to attract minorities to the sciences have come under attack as a result of the limitations currently imposed on affirmative action in higher education.[77] In an effort to avoid the threat of litigation or complaints,[78] many institutions no longer target programs solely to minority groups or use race-based eligibility criteria in awarding fellowships or participation in academic enrichment programs.[79] These programs that were formerly race-exclusive, have been opened to all students "... to serv[e] the broader and more abstract goal of promoting campus diversity."[80] Some institutions have even renamed their "minority" offices and programs as "diversity" or "multicultural" offices and programs.[81]

Women are also found to be underrepresented in selected science and engineering disciplines.[82] Although enrollment in rigorous course work and advanced placement classes in high school has increased for women in more than 10

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[76] (...continued)
college enrollment grew by 49%, to approximately 4.8 million students.

[77] In June 2003, the U.S. Supreme Court, in landmark cases involving the University of Michigan, Ann Arbor, defined the limits of affirmative action. See for example American Association for the Advancement of Science, National Action Council for Minorities in Engineering, Shirley M. Malcom, Daryl E. Chubin, Jolene K. Jesse, *Standing Our Ground, A Guidebook for STEM Educators in the Post-Michigan Era,* October 2004, 94 pp, Roach, Ronald, "Another Supreme Test?," *Diverse Issues in Higher Education*, v. 23, June 29, 2006, p. 8, and CRS Report RL31874, *The University of Michigan Affirmative Action Cases: Racial Diversity in Higher Education,* by Charles V. Dale.

[78] Complaints filed with the ED have accused institutions of violation of Title VI of the Civil Rights Act (prohibits discrimination in education), and Title VII of the Civil Rights Act (prohibits discrimination in employment by restricting fellowships for minority groups or for women).

[79] Some foundations, philanthropic organizations, and federal agencies no longer provide financial support to programs with race-exclusive eligibility criteria. See for example Jaschik, Scott, "Affirmative Action Challenged Anew,"Inside Higher Ed, April 8, 2008, [http://www.insidehighered.com/layout/set/print/news/2008/04/08/affirm], and Schmidt, Peter, "NIH Opening Minority Programs to Other Groups," *The Chronicle of Higher Education,* v. 51, March 11, 2005, p. A26.

[80] Schmidt, Peter, "From 'Minority' to 'Diversity'," *The Chronicle of Higher Education*, v. 52, February 3, 2006, p. A24. Daniel Rich, Provost, University of Delaware states that his institution has changed a scholarship program once reserved for racial or ethnic minorities. It is now opened to students who are first generation members to attend college, who have been classified as financial needy based on federal financial-aid calculations, or who have experienced "challenging social, economic, educational, cultural, or other life circumstances."

[81] Glater, Jonathan D., "Colleges Open Minority Aid to All Comers," *The New York Times*, March 14, 2006, and Schmidt, Peter, "Justice Dept. Is Expected to Sue Southern Illinois U. Over Minority Fellowships," *The Chronicle of Higher Education*, v. 52, November 25, 2005, p. A34.

[82] See House Committee on Science and Technology, Subcommittee on Research and Science Education, Hearing, *Fulfilling the Potential of Women in Academic Science and Engineering Act of 2008,* 110th Cong., 2nd Sess., May 8, 2008.

years, there is still a need to strengthen the course taking and persistence of women all along the educational pipeline.[83] Data reveal that in 2005, women were awarded approximately 50.5% of the undergraduate degrees in science and engineering, a slight decrease from 50.8% in 2002.[84] The number of women who persist in the science and engineering disciplines to the graduate level shows a decline. In 2005, 39.5% of the doctorate degrees in science and engineering were awarded to women, almost level with the 39.2% in 2002.[85] Disaggregated data find that these awards were concentrated in selected disciplines. In 2005, women were awarded 22.5% of the doctorate degrees in engineering, 26.7% in the physical sciences, and 19.8% in computer sciences. The proportion for these awards earned by women in 2002 were 17.5%, 26.6%, and 20.6%, respectively. In the social and behavioral sciences, women earned 55.0% of the doctorates in 2005, an increase from the 54.4% in 2002. There was even more significant participation by women in psychology. Women were awarded 68.0% of the doctorates in psychology in 2005, and 66.7% in 2002.[86]

Shirley Ann Jackson, President, Rensselaer Polytechnic Institute, states that in the "altered environment" resulting from the Supreme Court decisions, the nation is challenged more than ever to confront the changing demographics. Blacks, Hispanics, and women, groups underrepresented in the science, engineering, and technical disciplines, comprise more than 66% of the entire workforce. It is expected that this "new majority" will replace the impending retiring scientific and engineering workforce which is largely white and male.[87] Jackson notes that:

> [W]e are experiencing pressure to replace the graying science and engineering workforce with new talent — educated young scientists and engineers who will make the discoveries and innovations which have paid off so handsomely, to date.... While the recent Supreme Court decisions uphold diversity, they force us to come at things in a different way. We must come up with solutions for developing science and engineering talent — solutions that address the new and coming realities of the underrepresented minority becoming the underrepresented majority.[88]

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[83] Virnoche Mary E., "Expanding Girls' Horizons: Strengthening Persistence in the Early Math and Science Education Pipeline," *Journal of Women and Minorities in Science and Engineering*, v. 14, 2008, pp. 29-44; The National Academies, *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering*, Washington, 2007, pp. 59-60; Dean, Cornelia, "Women in Science: The Battle Moves to the Trenches," *The New York Times*, December 19, 2006; and Ripley, Amanda, "Who Says a Woman Can't Be Einstein?," *Time*, March 7, 2005, pp. 51-59.

[84] National Science Board, *Science and Engineering Indicators 2008,* Volume 2, Appendix Table 2-27.

[85] Ibid., Appendix Table 2-31.

[86] Ibid.

[87] More than half of the U.S. science and engineering workforce is over the age of 40.

[88] *Standing Our Ground, A Guidebook for STEM Educators in the Post-Michigan Era*, pp. 71-12.

Foreign Science and Engineering Students[89]

The increased presence of foreign students in graduate science and engineering programs has been and continues to be of concern to some in the scientific community.[90] Enrollment of U.S. citizens in graduate science and engineering programs has not kept pace with that of foreign students in those programs.[91] NSF data reveal found that first-time, full-time science and engineering graduate enrollment of foreign students in science and engineering disciplines increased by approximately 16.0% from 2005 to 2006. The increase for U.S. citizens and permanent resident students during this same academic year was slightly more than 1.0%. In addition to the number of foreign students in graduate science and engineering programs, a significant number of university faculty in the scientific disciplines are foreign, and foreign doctorates are employed in large numbers by industry.

NSF data reveal that in 2005, the foreign student population earned approximately 34.7% of the doctorate degrees in the sciences and approximately 63.1% of the doctorate degrees in engineering.[92] In 2005, foreign students on temporary resident[93] visas earned 20.6% of the doctorates in the sciences, and 48.6% of the doctorates in engineering. The participation rates in 2004 were 18.9% and 48.8%, respectively. In 2005, permanent resident[94] status students earned 3.8% of the doctorates in the sciences and 4.4% of the doctorates in engineering, an increase over the 2004 levels of 3.7% and 4.2%, respectively.[95] Trend data for science and engineering degrees for the years 1996-2005 reveal that of the non-U.S. citizen

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[89] For an expanded discussion of foreign scientists and engineers, see CRS Report RL31146, *Foreign Students in the United States: Policies and Legislation*, by Chad Haddal, CRS Report RL30498, *Immigration: Legislative Issues on Nonimmigrant Professional Specialty (H-1B) Workers*, by Ruth Ellen Wasem, and CRS Report 97-746, *Foreign Science and Engineering Presence in U.S. Institutions and the Laborforce*, by Christine M. Matthews.

[90] Scanlon, Cynthia, "The H-1B Visa Debate," *Area Development Site and Facility Plann*ing Online, October/November 2006, [http://www.areadevelopment.com/laborEducation/oct06/h1bvisa.shtml].

[91] National Science Foundation, *First-Time, Full-Time Graduate Student Enrollment in Science and Engineering Increases in 2006, Especially Among Foreign Students*, InfoBrief, NSF08-302, Arlington, VA, December 2007, 6 pp., and McCormack, Eugene, "Number of Foreign Students Bounces Back to Near-Record High," *The Chronicle of Higher Education*, v. 54, November 16, 2007, p. A1.

[92] National Science Foundation, *Science and Engineering Doctorate Awards: 2005*, Detailed Statistical Tables, NSF07-305, Arlington, VA, December 2006, Table 3.

[93] A temporary resident is a person who is not a citizen or national of the United States and who is in this country on a temporary basis and can not remain indefinitely. The terms nonresident alien or nonimmigrant are used interchangeably.

[94] A permanent resident ("green card holder") is a person who is not a citizen of the United States but who has been lawfully accorded the privilege of residing permanently in the United States. The terms resident alien or immigrant apply.

[95] *Science and Engineering Doctorate Awards: 2005*, Table 3.

population, temporary resident status students consistently have earned the majority of the doctorate degrees.

There are divergent views in the scientific and academic community about the effects of a significant foreign presence in graduate science and engineering programs.[96] Some argue that U.S. universities benefit from a large foreign citizen enrollment by helping to meet the needs of the university and, for those students who remain in the United States, the Nation's economy.[97]

> Foreign students generate three distinct types of measurable costs and benefits. First, 13 percent of foreign students remain in the United States, permanently increasing the number of skilled workers in the labor force. Second, foreign students, while enrolled in schools, are an important part of the workforce at those institutions, particularly at large research universities. They help teach large undergraduate classes, provide research assistance to the faculty, and make up an important fraction of the bench workers in scientific labs. Finally, many foreign students pay tuition, and those revenues may be an important source of income for educational institutions.[98]

Some argue that the influx of immigrant scientists and engineers has resulted in depressed job opportunities, lowered wages, and declining working conditions for U.S. scientific personnel. While many businesses, especially high-tech companies, have recently downsized, the federal government issued thousands of H-1B visas to foreign workers. There are those in the scientific and technical community who contend that an over-reliance on H-1B visa workers to fill high-tech positions has weakened opportunities for the U.S. workforce.[99] Many U.S. workers argue that a number of the available positions are being filled by "less-expensive foreign labor."[100] Those critical of the influx of immigrant scientists have advocated placing

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[96] See for example The National Academies, Committee on Science, Engineering, and Public Policy, *Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States*, Washington, DC, 2005, pp. 17-65, Kalita, S. Mitra and Krissah Williams, "Help Wanted as Immigration Faces Overhaul," *The Washington Post*, March 27, 2006, p. A01, Clemons, Steven and Michael Lind, "How to Lose the Brain Race," *The New York Times*, April 10, 2006, Wertheimer, Linda K., "Visa Policy Hinders Research; Hurdles for Foreign Students Take Toll on Colleges' Scientific Work," *The Dallas Morning News*, November 24, 2002, p. A1, Stephan, Paula E. and Sharon G. Levin, "Exceptional Contributions to U.S. Science by the Foreign-Born and Foreign-Educated," *Population Research and Policy Review*, v. 20, 2001, pp. 59-79.

[97] The Institute of International Education reports that for the 2006/2007 academic year, foreign students and their families contributed approximately $14.5 billion to the U.S. economy in money from tuition, living expenses and related costs. The Department of Commerce estimates that U.S. higher education is the nation's fifth largest service sector export. Institute of International Education, *Open Doors 2007: International Students in the United States*, November 13, 2007, [http://opendoors.iienetwork.org/?p=113743].

[98] Borjas, George, Center for Immigration Studies, *An Evaluation of the Foreign Student Program*, June 2002, [http://www.cis.org/articles/2002/back602.htm], pp.6-7.

[99] See for example Schwartz, Ephraim, "H-1B: Patriotic or Treasonous?," *InfoWorld*, v. 27, May 6, 2005, [http://www.infoworld.com/article/05/05/06/19NNh1b_1.html].

[100] Johnson, Carrie, "Hiring of Foreign Workers Frustrates Native Job-Seekers," *Washington*

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restrictions on the hiring of foreign skilled employees in addition to enforcing the existing laws designed to protect workers. Those in support of the H-1B program maintain that there is no "clear evidence" that foreign workers displace U.S. workers in comparable positions and that it is necessary to hire foreign workers to fill needed positions, even during periods of slow economic growth.[101]

The debate on the presence of foreign students in graduate science and engineering programs and the workforce has intensified as a result of the terrorist attacks of September 11, 2001. It has been reported that foreign students in the United States are encountering "a progressively more inhospitable environment."[102] Concerns have been expressed about certain foreign students receiving education and training in sensitive areas.[103] There has been increased discussion about the access of foreign scientists and engineers to research and development (R&D) related to chemical and biological weapons. Also, there is discussion of the added scrutiny of foreign students from countries that sponsor terrorism.[104] The academic community is concerned that the more stringent requirements of foreign students may have a continued impact on enrollments in colleges and universities.[105] Others contend that

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[100] (...continued)
Post, February 27, 2002, p. E01.

[101] See for example Clark, John, Nadine Jeserich, and Graham Toft, Hudson Institute, *Can Foreign Talent Fill Gaps in the U.S. Labor Force? The Contributions of Recent Literature*, September 2004, 33 pp., Baker, Chris, "Visa Restrictions Will Harm U.S. Technology, Gates Says; Microsoft Chief Calls For End to Caps On Workers," *The Washington Times*, April 29, 2005, p. C13, and Frauenheim, Ed, "Brain Drain in Tech's Future?," CNET Nets.com, August 6, 2004.

[102] Hudson, Audrey, "Foreign Students Labeled 'Threats'," *The Washington Times*, June 24, 2008, p. A1, and House Committee on the Judiciary, Subcommittee on Immigration, Border Security, and Claims, *Sources and Methods of Foreign Nationals Engaged in Economic and Military Espionage*, 109th, 1st Sess., September 15, 2005, Written testimony of William A. Wulf, President, National Academy of Engineering, p. 12, and Foroohar, Rana, "America Closes Its Doors," [http://msnbc.msn.com/id/6038977/site/newsweek/print/1/displaymode/1098].

[103] See for example Lang, Les, "Commerce Department Withdraws Extra Restrictions on Foreign Scientists," *Gastroenterology*, v. 131, October 2006, p. 988, and NAFSA: Association of International Educators, *Restoring U.S. Competitiveness for International Scholars*, June 2006, p. 6. The Bureau of Consular Affairs, Department of State, issues visas to foreign students and maintains a "technology alert list" that includes 16 sensitive areas of study. The list was produced in an effort to help the United States prevent the illegal transfer of controlled technology, and includes chemical and biotechnology engineering, missile technology, nuclear technology, robotics, and advanced computer technology.

[104] The State Department publishes a list annually of state sponsors of terrorism. Currently, the countries include Cuba, Iran, Libya, North Korea, Sudan, and Syria. CRS Report RL32251, *Cuba and the State Sponsors of Terrorism List*, by Mark P. Sullivan.

[105] See for example Cohen, David, "Middle Eastern Students Shut Out of the U.S. Turn to Australia and New Zealand," *The Chronicle of Higher Education*, v. 53, August 17, 2007, p. A37, Strauss, Valerie, "Competition Worries Graduate Programs," *The Washington Post*,
(continued...)

a possible reduction in the immigration of foreign scientists may affect negatively on the competitiveness of U.S. industry and compromise commitments made in long-standing international cooperative agreements.[106]

Congressional Activity[107]

On August 9, 2007, President Bush signed into law P.L. 110-69, The America COMPETES Act (H.R. 2272).[108] The legislation is directed at increasing research investment, improving economic competitiveness, developing an innovation infrastructure, and strengthening and expanding science and mathematics programs at all points on the educational pipeline. This legislation includes components of other competitiveness bills introduced in the 110th Congress. The COMPETES Act authorizes $33.6 billion for FY2008 through FY2010 for science, mathematics, engineering, and technology programs across the federal government. Among other things, it directs the NSF to expand the Integrative Graduate Education and Research Traineeship and the Graduate Research Fellowship programs, and to establish a clearinghouse of programs related to improving the professional science master's degree. To address the need to expand the participation of underrepresented groups in the sciences, the COMPETES Act supports a program for mentoring to women interested in pursing degrees in science, mathematics, and engineering. In addition, it requires the NSF to establish teacher institutes that are focused on science, technology, engineering, and mathematics. These are to be summer institutes and are to provide professional development for teachers at the precollege level teaching in high-need subjects and in high-need schools.

Additional legislation introduced during the 110th Congress includes H.R. 4151, the STEM Promotion Act of 2007. This bill is directed at expanding the pipeline of U.S. students pursuing degrees in science, technology, engineering, or mathematics education. The degree fields are those deemed necessary to meet the workforce

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105 (...continued)
April 18, 2006, p. A06, and The National Academies, *Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States*, pp. 26-42.

106 "Current Visa Restrictions Interfere with U.S. Science and Engineering Contributions to Important National Needs," Statement from Bruce Alberts, President National Academy of Sciences, Wm. A. Wulf, President, National Academy of Engineering, and Harvey Fineberg, President, Institute of Medicine, December 13, 2002 [http://www.nationalacademies.org]. See also Southwick, Ron, "Agriculture Department Draws Fire for Decision to Stop Hiring Foreign Scientists," *The Chronicle of Higher Education*, v. 48, May 13, 2002.

107 For expanded discussion of legislative action related to science and engineering education issues, see CRS Report RL33434, *Science, Technology, Engineering, and Mathematics (STEM) Education: Background, Federal Policy, and Legislative Action*, by Jeffrey J. Kuenzi.

108 COMPETES — Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science. For expanded discussion of science and mathematics programs in the COMPETES Act, see CRS Report RL34396, *The America COMPETES Act and the FY2009 Budget*, and CRS Report RL34328, *America COMPETES Act: Programs, Funding, and Selected Issues*, both by Deborah D. Stine.

demands and economic competitiveness of the nation. H.R. 4151 would make specific recruitment efforts at those groups who are underrepresented in the STEM disciplines — blacks, Hispanics, Native Americans, and women. H.R. 6104, S. 3047, Enhancing Science, Technology, Engineering, and Mathematics Education Act of 2008, would seek to enhance coordination of STEM education initiatives and foster cooperation between the states and federal government. The bills would include initiatives to improve teacher preparation programs at institutions of higher education by incorporating promising practices and programs that foster student learning and problem solving skills. H.R. 1467, the 10,000 Trained by 2010 Act, would authorize funding for competitive grants to institutions to establish and offer education and training programs in the areas such as information studies, population informatics, and data security, integrity, and confidentiality. Student internships and bridge programs would be established in these research areas at the state, local and federal level, and in the private sector.

Oversight by the 110th Congress may touch on some of the following questions: Can our system of education and training achieve its stated goal of being first in science and mathematics? Can underrepresented minorities be encouraged to pursue scientific careers in larger numbers? Can the U.S. continue to produce successive generations of scientists, engineers, and technicians to meet the demands of the nation's changing economy and workplace?