



REPORT TO THE PRESIDENT
AND CONGRESS

DESIGNING A DIGITAL FUTURE:
FEDERALLY FUNDED RESEARCH
AND DEVELOPMENT IN
NETWORKING AND INFORMATION
TECHNOLOGY

Executive Office of the President
President's Council of Advisors on
Science and Technology

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8.2 Education and Human Resources

Finding: All indicators – all historical data, and all projections – argue that NIT is the dominant factor in America’s science and technology employment, and that the gap between the demand for NIT talent and the supply of that talent is and will remain large. Increasing the number of graduates in NIT fields at all degree levels must be a national priority. Fundamental changes in K-12 education are needed to address this shortage.

NIT workforce: Robust demand, limited supply. NIT workforce supply and demand has been the subject of a significant amount of thoughtful analysis and of a far greater amount of editorializing in the press. Two recent thoughtful analyses are Chapter 4 of the 2009 National Academies report *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem*⁶⁷ and a 2009 report prepared for

66. <http://www.washingtonpost.com/wp-dyn/content/article/2007/01/30/AR2007013002065.html>

67. National Academies Press. (2009). *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem: Retaining Leadership in an Increasingly Global Environment*.

NITRD by SRI⁶⁸. It is clear from the available data that NIT workers are a significant part of the Nation's workforce and a dominant part of the Nation's S&T workforce. It is also clear that the Nation is not granting enough degrees in NIT fields to fill the available jobs.

Estimates of the number of employees in NIT occupations in the United States differ due to definitional variations. A reasonable but conservative estimate is 3.8 million. On the U.S. Bureau of Economic Analysis (BEA) definition of NIT, there were 3.79 million full time equivalent employees in NIT occupations in the United States in 2008 (the number rises to 3.99 million if part time employees are included).⁶⁹ Filtering U.S. Bureau of Labor Statistics (BLS) data⁷⁰ on BLS job codes corresponding to NIT occupations yields an estimate of 3.81 million workers. At the high end, applying the Organization for Economic Cooperation and Development (OECD) definition of NIT⁷¹ to BEA data yields an estimate of 5.84 million full time equivalent employees.

NIT workers represent a majority of the Nation's S&T workforce. Data from BLS show that NIT occupations have comprised between 52% and 58% of all S&T occupations from 1998 to 2008.⁷² To understand the significance of this statement, it is important to recognize that S&T occupations include all engineering, life science, physical science, and social science occupations.⁷³

The most authoritative employment demand projections are made semi-annually by the BLS. The most recent projections, issued in November 2009, cover the ten-year period 2008-2018.⁷⁴ That report states (p. 85):

Computer and mathematical occupations are expected to add 785,700 new jobs from 2008 to 2018, and, as a group, they will grow more than twice as fast as the average for all occupations in the economy, according to projections. It is anticipated that computer specialists will account for the vast majority of this growth, increasing by 762,700 jobs. Demand for computer specialists will be driven by the continuing need for businesses, government agencies, and other organizations to adopt the latest technologies... New computer specialist jobs will arise in almost every industry...

Figure 8.2-1 shows BLS projections for job growth in five major S&T categories between 2008 and 2018. For each field, "New Jobs" represents expansion while "New Jobs + Replacements" represents total available positions. The dominance of NIT ("Computer specialists") is clear.

68. SRI International. (May 29, 2009). *Networking and Information Technology Workforce Study: Final Report*. http://www.nitrd.gov/About/NIT_Workforce_Final_Report_5_29_09.pdf

69. U.S. Bureau of Economic Analysis. (2009). "Bureau of Economic Analysis, Gross Domestic Product by Industry." http://www.bea.gov/industry/xls/GDPbyInd_VA_NAICS_1998-2009.xls

70. U.S. Bureau of Labor Statistics. (2009). "May 2009 National Occupational Employment and Wage Estimates United States." http://www.bls.gov/oes/current/oes_nat.htm

71. Organisation for Economic Cooperation and Development. (2008). (page 3). *OECD Information Technology Outlook 2008*.

72. U.S. Bureau of Economic Analysis. (2009). "Bureau of Economic Analysis, Gross Domestic Product by Industry." http://www.bea.gov/industry/xls/GDPbyInd_VA_NAICS_1998-2009.xls

73. BLS codes 15-0000 through 19-0000.

74. "Occupational employment projections to 2018." (November 2009). *Monthly Labor Review*, U.S. Bureau of Labor Statistics.

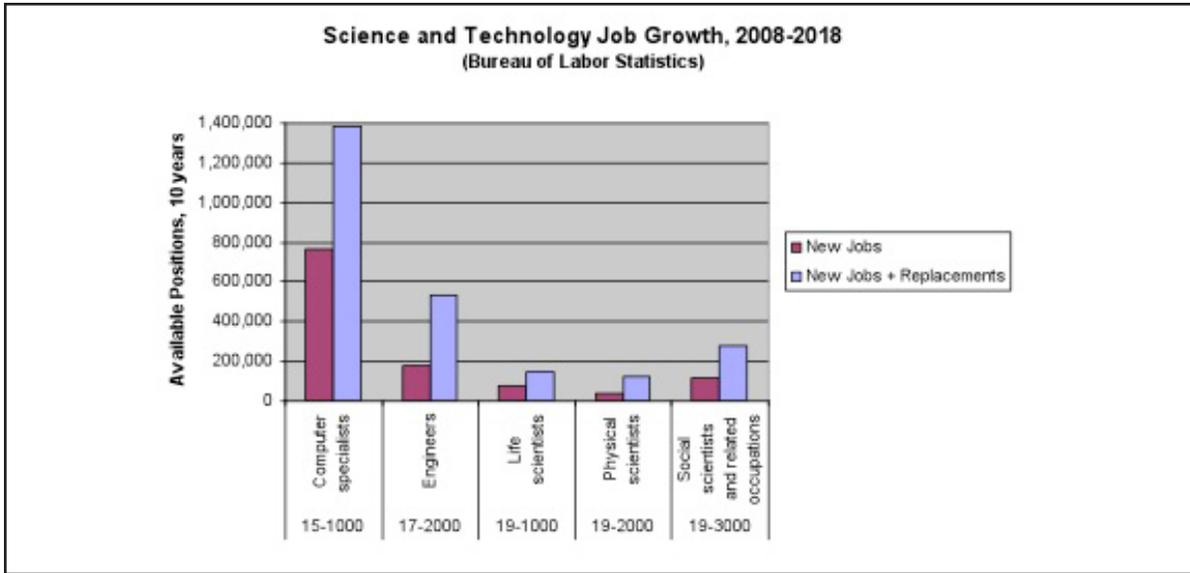


Figure 8.2.1

To summarize the demand side of the equation: While there will be inevitable variations in demand for every field, the long-term prospects for employment in NIT occupations in the United States are exceedingly strong. All other S&T fields pale by comparison.

The supply side of the equation is a cause of great concern. Figure 8.2-2 shows NSF statistics for degrees granted in 2006 in the S&T fields corresponding to the five BLS categories.⁷⁵ Degrees in psychology and the social sciences dominate, with degrees in other S&T fields lagging far behind.

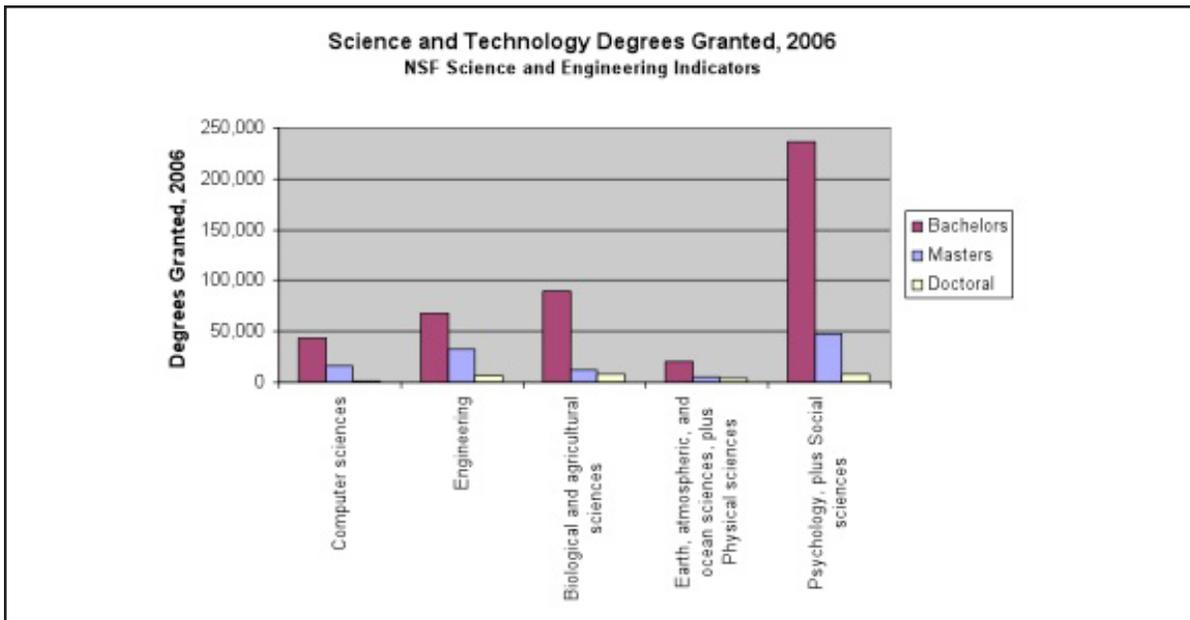


Figure 8.2.2

75. National Science Foundation, Division of Science Resources Statistics. (October 2008). Science and Engineering Statistics, S&E Degrees. (1966-2006). http://www.nsf.gov/statistics/nsf08321/content.cfm?pub_id=3785&id=2

It is difficult to make direct field-by-field comparisons between available jobs and degrees granted: Individuals with degrees in many fields work in NIT occupations, and individuals with NIT degrees work in many fields. With this important caveat, Figure 8.2-3 compares annualized job openings (BLS data) to total annual degrees granted (NSF data) for the five S&T fields reported in the previous two figures. Recent ACT data show an even greater disparity between declared student interest in computing majors and job growth predictions.

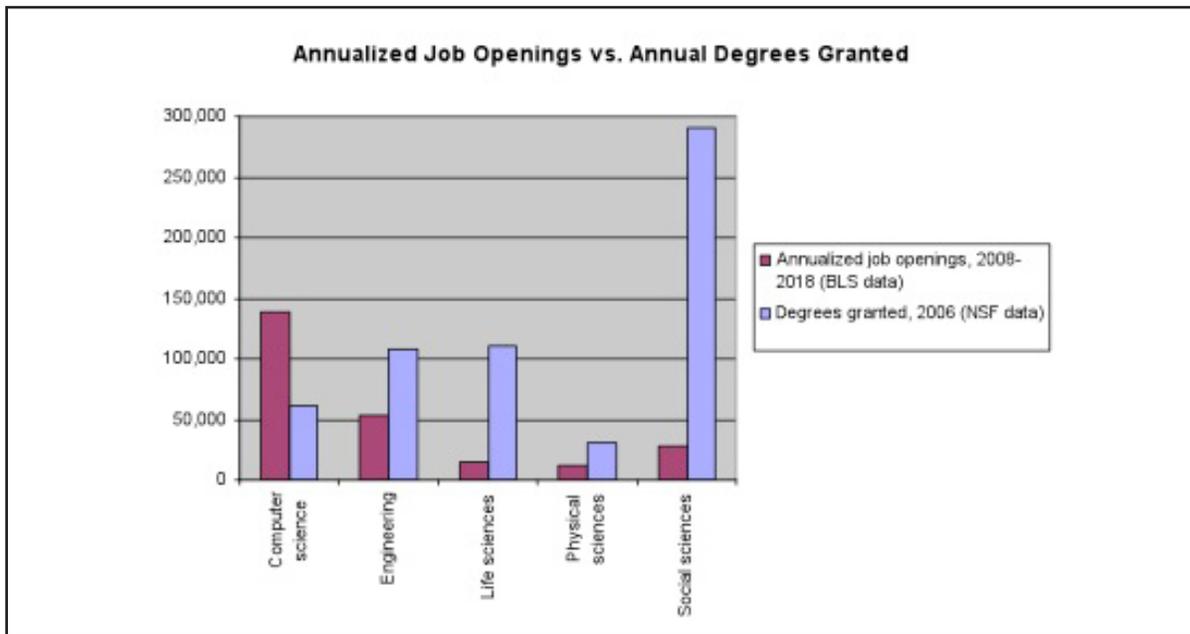


Figure 8.2.3

Understanding information technology – fluency, computational thinking, computer science. NIT pervades modern life. Every citizen – not just the NIT professional – needs to be fluent with information technology. The various dimensions of “NIT fluency” were the subject of a landmark 1999 National Academies study⁷⁶ that has stood the test of time remarkably well.

Fluency obviously involves a set of skills, such as using a word processor or spreadsheet, using the Internet to find information and resources, and using a database system to set up and access information. But fluency also involves a set of concepts and capabilities that have little to do directly with the use of a computer, but rather have to do with “computational thinking.”⁷⁷ Basic concepts of computational thinking include abstraction, modeling, algorithmic thinking, algorithmic efficiency and analysis, stepwise fault isolation, and universality. Basic capabilities include algorithmic expression, managing complexity, and evaluating information. The skills, concepts, and capabilities of NIT are illustrated in the sidebar, taken from the National Academies study.

To illustrate the impact of computational thinking, consider two fields, linguistics and biology. Linguistics was transformed in the 1960s by the introduction of formal grammars, due to Chomsky and others – classic computational thinking. Biology was transformed beginning at about the same time, but extending

76. National Academies Press. (1999). *Being Fluent with Information Technology*.

77. Jeannette M. Wing. (March 2006). “Computational Thinking.” *Communications of the ACM* 49,3, pp. 33-35.

over a longer period, by Watson and Crick's discovery that the human genome was a biochemically-implemented digital code; this discovery, and countless subsequent technological and conceptual breakthroughs, transformed biology into an information science.

The term "computer science" has traditionally meant the academic specialization that prepares NIT professionals. But this old characterization needs to be extended. Just as learning mathematics includes everything from children learning to count to post-docs studying algebraic topology, so learning computer science should be understood as gaining a full spectrum of skills from the elements of fluency to the most advanced graduate concepts. The recent PCAST report on Science, Technology, Engineering, and Mathematics (STEM) education also argues for a deeper understanding of computer science⁷⁸:

Computer-related courses should aim not just for technological literacy, which includes such utilitarian skills as keyboarding and the use of commercial software packages and the Internet, but for a deeper understanding of the essential concepts, methods and wide-ranging applications of computer science. Students should gain hands-on exposure to the process of algorithmic thinking and its realization in the form of a computer program, to the use of computational techniques for real-world problem solving, and to such pervasive computational themes as modeling and abstraction, modularity and reusability, computational efficiency, testing and debugging, and the management of complexity.

If Americans are to acquire proficiency in all levels of computing, their education must begin when they are children. Fluency with NIT skills, concepts, and capabilities; facility in computational thinking; and an understanding of the basic concepts of computer science must be an essential part of K-12 STEM education.

Advancing STEM education. Many previous studies of the NIT workforce^{79,80} have emphasized the importance of visas in addressing America's NIT workforce gap. Between 40% and 50% of the 214,271 H-1B petitions approved in Fiscal Year 2009 were for workers in computer-related occupations.⁸¹

This need for imported NIT expertise persists. However, the Nation must be more aggressive in pursuing a long-term solution by developing the necessary expertise in the American populace. It is our view that such a solution must begin with dramatic enhancements to K-12 STEM education. Since K-12 STEM education is the focus of the PCAST report cited above, we will not discuss it further here, except for a brief elaboration on the role of computer science in STEM.

Today, K-12 education largely ignores computer science. Most high school computing courses, teach only basic literacy – the use of word processors, spreadsheets, etc. Those courses are typically taught

78. President's Council of Advisors on Science and Technology. (September 2010). *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future*. <http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf>

79. National Academies Press. (2009). *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem: Retaining Leadership in an Increasingly Global Environment*.

80. President's Council of Advisors on Science and Technology. (August 2007). *Leadership Under Challenge: Information Technology R&D in a Competitive World*. An Assessment of the Federal Networking and Information Technology R&D Program. <http://www.nitrd.gov/pcast/reports/PCAST-NIT-FINAL.pdf>

81. U.S. Department of Homeland Security. (April 15, 2010). *Characteristics of H-1B Specialty Occupation Workers: Fiscal Year 2009 Annual Report*.

on the Career and Technical Education (CTE) track, and thus are not attractive to most college-bound students. Even schools that do provide academic computing courses appropriate for college preparatory students generally offer them as electives; few states count computing as a math or science requirement. Nationwide, fewer than 8% of our schools offer Advanced Placement (AP) Computer Science. Few K-12 computing teachers have any formal background in computing. To build a competitive, global workforce we will need to do much better than this.

All students – but most certainly all STEM students – will need a firm grounding in computing. They will need a level of sophistication that goes well beyond merely being able to use computational systems and devices. They will need to be able to “bend” computation to their purposes. To reach this level, all high school students must have the opportunity to take rigorous, academic computing classes. Computing must thoroughly infuse the K-12 curriculum, so that students have an opportunity to understand the role of computing in solving problems in many disciplines. As an example, students often use off-the-shelf simulations in biology or physics classes, but the experience would be much richer if it went beyond just filling in numbers and seeing the results. Students would be enriched by an understanding of what a simulation is: What is an abstraction? How are simulation models developed? How are they tested and validated?

To teach computing either as a separate discipline or as content infused across the curriculum, we will need better prepared teachers. As a Nation we must undertake an aggressive, and perhaps unprecedented, effort to prepare teachers who can effectively teach computing. We should support all of this with state-of-the-art online learning and social communities both for the teachers and their students.