The Future of Information Technology

Growing the Talent Critical for Innovation

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By the Numbers

$1 trillion	Worldwide overinvestment in fiber optics, coinciding with Y2K IT challenges[1]
2000	Last year of the “dot-com bubble”
-39%	Overall decrease in the number of U.S. students choosing Computer Science as a major since 2000[2]
-60%	Decrease in students choosing Computer Science as a major between 2000-2004[3]
-70%	Decrease in incoming freshmen Computer Science majors since a peak in the early 1980s[4]
1.1 million	U.S. high school seniors taking a college entrance exam in 2002[5]
6%	U.S. high school seniors planning to pursue a degree in Engineering in 2002[6]
-33%	Decrease in U.S. high school seniors planning to major in Engineering from the 1990’s to 2002[7]
5%	Yearly growth in U.S. jobs requiring engineering skills[8]
1%	Average yearly growth in all job categories in the U.S.[9]
3rd	Rank by wages of Computing & Mathematical occupations, compared to *all* jobs in the U.S.[10]
1.5 million	Anticipated increase in jobs available in Computing and IT in the U.S. by 2012[11]
15.6%	U.S. male freshmen intending to major in Engineering in 2006[12]
2.6%	U.S female freshmen intending to major in Engineering in 2006[13]
0.3%	U.S. female freshmen intending to major in Computer Engineering in 2006[14]
0.2%	U.S female freshman intending to major in Electrical/Electronic Engineering in 2006[15]
1/6	South Korean population, compared to the population of the U.S.[16]
60,000	Number of engineers graduating yearly in both South Korea and the U.S.[17]
700,000	Number of engineers graduating yearly from Chinese universities[18]
90%	Predicted proportion of the world’s scientists and engineers living in Asia by 2010[19]
43%	Non-resident alien graduate students in the U.S. and Canada majoring in Computer Science and Engineering[20]
90%	Proportion of Computer Science students who could benefit from learning computational theory in context[21]
7%	Percentage of female Computer Science undergraduates at CMU in 1995[22]
42%	Percentage of female Computer Science undergraduates at CMU in 2000, after policy changes[23]

Key Findings

I. For students, there are multiple causes for the decline in interest in the computing professions

- Students perceive opportunities in computing as rapidly vanishing
- The poor image of computing professions and inadequate information contribute to the decline
- Gender equity issues are a factor in the decline
- A poor early education leaves many unprepared for and disinclined to the computing fields

II. A crisis in competitiveness is fast approaching

- Investment in academic research is steadily shrinking
- The IT industry is experiencing difficulties in recruiting talent
- Growth in the IT industry abroad is accelerating dramatically
- Loss of thought leadership is imminent
- IT students immigrating to the U.S. no longer fill the gap

III. A multi-pronged solution strategy is called for

- Seven different audiences must be influenced to create positive change in the computing fields
- Overall public awareness must be increased
- A national initiative is desperately needed
- Get accurate data to students today; wrong information is discouraging them
- Compelling curriculum and educational models must be created
- Practices to encourage women to enter the computing fields must be immediately and broadly adopted
- Immigration Policies must be improved

IV. Recommendations & Conclusion

- Public and political determination is critical
- Specific programs and practices must be implemented soon
- Implications
- Systemic change is needed
- Augustine Report Recommendations
- Solution Scope varies from industry to industry, segment to segment
- Combined efforts by all sectors are essential to success

A Critical Pipeline for Innovation

The sciences, engineering, and computing drive technological and economic progress but must rely on a diminishing supply of highly trained talent

Advances in Computer Science and Information Technology have been the principal drivers of significant economic growth worldwide for more than two decades. Currently, the United States is in a position of thought leadership in these professions, but a dramatic decline has begun in the number of CS and IT graduates available domestically.

The actual demand for qualified people to staff computing positions in the U.S. continues to increase, but funds for academic research and education are disappearing, signaling an impending loss of national competitiveness.

The general appeal of the computing disciplines to students is also on the wane, impacted by the field's poor image and perceptions about disappearing jobs and global competition. Contributing significantly to this downward trend is the lack of adequate math and science preparation in grades K-12, a sharp decrease in the number of women drawn to computing, and increasingly stringent immigration policies.

An examination of the causes for this decline in computing professionals, and the impact this will have on industry in the U.S. and on our intellectual leadership in this field indicates an urgent need for immediate and sustained remedies in several areas. Addressing this dire situation will require concerted action by members of academia, industry, and government, and by individual citizens. This paper is intended to provide ideas for action, and to review some promising efforts to alleviate various aspects of this problem and to reverse these trends.

While some of the most valuable improvements necessitate the participation of academia, and other efforts can benefit strongly from industry involvement, the most important overall need is for a determined national initiative focused on implementing proven practices to alleviate this problem.

The Student Perspective

Students perceive multiple signs of a decline in opportunity in the computing professions

Where Is The Next Generation?

Currently, there is a serious decrease in the number of students entering the computing disciplines in the United States. The most dramatic decline can be seen in Computer Science enrollment, which has plummeted in the United States in the last few years by 30%.[24] Despite this decline, computing is what drives the economy: Grady Booch, an IBM fellow and author of several books on software programming, predicts that for the next twenty years, "Every advance we can anticipate is going to require software that has not yet been written".[25] However, interest in employment in the tech sector continues to slow despite the fact that, "Advances in IT drive advances in all other fields, advances in IT power our economy, advances in IT are the cornerstone of our national security [and] IT is where the jobs are." [26]

What Is Driving Students Away?

This decline affects Computer Science and related disciplines at both the undergraduate and graduate levels. The predominant scope of this discussion centers on U.S. student populations, although there is significant interdependency with other important regional student trends abroad. The decline in students interested in the computing fields is primarily related to the following three factors, listed in order of priority:

- The prevailing perception among students that opportunity is disappearing
- A serious decline in the general appeal of the computing professions
- Specific discouragement that prevents the following two student populations from participating fully:
- Women are discouraged from entering this field by the unattractive image of computing and also discouraged from continuing in this field by specific practices
- Foreign students are discouraged by tightening immigration restrictions

The Story of Vanishing Opportunities

One of many outcomes of the market decline in technologies is that students are wary of a career in computing. The bursting of the "dotcom bubble" at the beginning of the 21st century, which was one of the top 10 stories reported on in 2001, led to distrust in the stock market and to a decreased emphasis on technology sector investment.[27]

Although technological advances are important in moving economies forward, even strong technology companies have been grouped together in the minds of many with the numerous, highly speculative businesses that were focused on Internet commerce get-rich-quick schemes.

The bursting of the dotcom bubble led to increased wariness among potential IT students

Many Internet commerce ventures focused on a "build it, and they will come" philosophy and were driven by the urgent need to "get there first", which resulted in a plethora of well-publicized business failures. While becoming more wary of these tenuous, speculative opportunities, investors diverted their attention away from solid and truly innovative technology companies seriously affecting public perceptions of the IT industry. This negative perception is not limited to the U.S.; Canadian students have similar beliefs: "… a growing number of… students and grads [are] steering away from tech-sector jobs, presuming the industry is still in a post-bubble slump, with little in the way of employment opportunities. It's a disconnect that Bernard Courtois, president and CEO of the Information Technology Association of Canada, finds disturbing. 'People only retain that the bubble burst.' " [28] The overall effect on undergraduate students has been dramatic: "While the need for technical expertise is growing, the number of students choosing computer science as a major is 39 percent lower than in the fall of 2000, the last of the dot-com bubble years, according to the Computing Research Association".[29]

The Student Perspective

Negative News Coverage

Outsourcing is also a concern for potential students in part because of frequent mention of job outsourcing as a result of the increasing globalization of the work force. "In part, off shoring is gaining momentum because of news coverage," observes VP Stephanie Moore of Forrester Research.[30]

Outsourcing is no longer restricted solely to jobs related to automobiles, textiles, shoes and other manufactured goods, but now also includes IT products and services. The well-publicized doldrums in the technology sector of the equities market strongly reinforces the perception among students that opportunities in the computing occupations are diminishing. Some speculate that there may soon be no employment or leadership opportunities left in the computing professions in North America.

Year 2000 IT Investment Implications

Competition became truly global overnight

Huge IT and communications infrastructure upgrades have leveled the playing field worldwide. The Y2K phenomenon was characterized by fear of a possible catastrophic failure of legacy computer systems incapable of handling calendar dates after 1999. This generated a massive investment in computing infrastructure, which coincided with a $1 trillion overinvestment in optic fiber worldwide.[31] In turn, this advanced communication capability leveled the playing field for IT practitioners in India, China, Russia and other former Soviet republics, and in countries around the world.[32]

U.S domestic capacity was considerably stretched because a huge number of IT and programming tasks had to be completed before midnight on the last day of 1999, which led to some outsourcing of this very critical work. The skill and speed with which the outsourced work was performed, and the quality of the resulting output led to much wider recognition and acceptance of overseas technical abilities. The doors had finally opened, enabling an even greater level of outsourcing of a wider number of tasks. This resulted in significantly increased confidence in, and reliance upon, a global computing workforce rather than one which was primarily domestic.[33]

Students Have Incomplete Information

News focuses on globalization dangers while ignoring robust domestic growth projections

Where is the other part of the story? When domestic job loss is the primary emphasis, there is less time for coverage of other themes. Intentional or not, this skew in the coverage of this issue has increased students' fears beyond what the facts support. There are a number of other components contributing to global employment trends which are not as frequently discussed as outsourcing. For instance, the large increase in the number of computer professionals in India and China is not only a result of the fact that jobs were shipped there from the U.S., but also because employable technologists are no longer leaving these countries to go abroad at the previous rates. It professionals do not need to come to the U.S. for an education, nor must they look for a job only in the U.S. and other developed countries.

The strong increase in the anticipated need for domestic practitioners in the United States, while a common topic of conversation in industry and academia, is not widely known to the public at large. This has led to the prevailing conventional wisdom that there is no longer a viable career path available domestically in the computing professions. Ironically, although strong evidence of increasing demand now contradicts these commonly held perceptions, the data has not yet been widely publicized.

Fears of Asymmetrical Competition

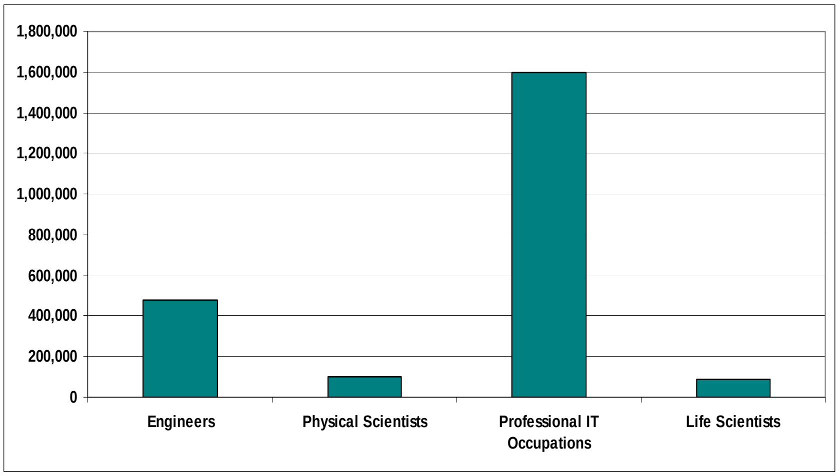
It is no wonder then, that students in the U.S. view computer programming and related computing jobs as one more occupation that has fallen victim to the global outsourcing phenomenon. Anecdotal information gleaned from discussions with U.S. colleges over a number of years indicates that fear of global competition motivates many decisions for undergraduates faced with these asymmetrical forms of competition. When others abroad can do the same work at a much lower cost, supported by a very capable communications infrastructure, the prospects for employment may seem grim indeed to U.S. students.

The Student Perspective

Misperceptions about Domestic Job Growth

Students are being drawn to professions with less employment opportunity due to incorrect perceptions of where professional opportunities lie. Although the playing field is being leveled, the domestic need to fill computing positions is increasing at a greater rate than the computing work that will be done abroad.[34] Meanwhile, students concerned with foreign competition are drawn to other computationally-intensive professions which they perceive as associated with growth industries, such as Bioinformatics. While the health sciences and biomedical industries as a whole are growing significantly, the CS and IT work available in these fields is experiencing only modest increases. Moreover, employment opportunities in these fields is relatively small, compared to the current and anticipated job demand in the more traditional computing fields as illustrated in the following graph.

Total Job Openings [IT, Science and Engineering Occupational Projections, 2002-2012][35]



Lack of Grand Challenges

Computing is losing its luster for many students. Lack of a broad, high-impact vision for the field is emerging as a major issue. Peter Lee interviews all new students at Carnegie Mellon University. What he finds is that they choose computing not for the job opportunities, and not for love of programming, but rather because they have some compelling social vision of what they can do with their education. He believes that "CS, in the public eye, is associated with computer programming and 'mundane' applications" and that "CS education has failed to evolve adequately over the past decade." [36] In addition, he says, "researchers have neglected the public, and hence our 'Grand Intellectual Challenges' have been forgotten." [37] Meanwhile, Lee points out that there are many opportunities for grand challenges and observes that, actually, "CS is wonderful!" He goes on to list some of the grander and more exciting problems that CS is addressing, including:

- The nature of human cognition/intelligence
- Design and verification of complex systems
- Autonomous systems
- Quantum computing
- Molecular-scale devices[38]

Principles First, Relevance Later

Students complain about spending so much time learning about the principles of programming before actually applying them. However, this may be more of a problem in some places than others, as Edward Lazowska, Chair of Computer Science and Engineering at the University of Washington points out: "This is not the way we teach our computer science students, and it's also not a complaint that I hear."[39]

The Student Perspective

In some schools, Computer Science and related disciplines focus on programming principles for the initial year or two of undergraduate study. The integration of these principles to solve more tangible problems was often deferred until later, delaying the illustration of relevance. Students change majors when the applicability of this curriculum is not apparent early enough in their college experience.

Students benefit from seeing the relevance of computing

In the study “Computing with Relevance” [40] Wayne Brookes observes that “In computer science education, the topic of computing theory is one that is commonly not well received by students. Career-oriented students often view the topic as irrelevant, and would rather learn new skills and technologies that they perceive will improve their future employment prospects”. Conversations with those enrolled in the Microsoft Research Student Consultant program also revealed this as common complaint from a number of schools in the United States.

One successful approach to this issue has been to adopt a problem-based learning model (Hamilton, Harland & Padgham, 2003).[41] Brookes’ conclusion indicates that student frustration is mitigated by principles presented in context: “Past experience shows that when taught in a standalone subject on computing theory, students often struggle with seeing the relevance of the material presented, even when many good examples are shown.” [42] Students are encouraged to learn specific aspects of computing principles in a context where their relevance can best be demonstrated. “This survey indicated that 90% of the students who responded could see the relationship of theory to practice ‘about half the time’ or more, with 58% seeing the relationship ‘usually’ or ‘always’ ” [43]

Relevance of Other Fields

Although real demand is growing in traditional computing areas, many other new disciplines may seem more attractive to students. Interdisciplinary fields which regularly employ computational methods to solve problems in their domains offer opportunities for earlier practical application and are often perceived by students as the real growth areas in terms of employment opportunity. These careers are usually available through graduate programs, and include Health Sciences, Bioinformatics, Medical Engineering, Computational Linguistics, Astronomy, Forensic Sciences and a number of other disciplines. Interestingly, these all include computationally intensive components, but only a few areas are featured in popular culture, for instance, in crime investigation stories. Lack of more valid information increases the influence of mass media on students, as noted by Charles McCamant, head of Angelo State's Computer Science Department. In the absence of better information, he says, "Things on TV guide their interests." [44]

Cultural Ambivalence

More difficult to estimate and assess are factors of cultural preference and opinion. In the United States, esteem for the computing professions is mixed. Stories are frequently told that computer scientists are admired for their intellectual and technical skills, but also routinely associated with the stereotype of predominantly male, immature, badly groomed, socially dysfunctional misfits. In addition, computing is viewed by many as a very hard course of study in school, and also a hard field in the workplace, where “hard” is defined not merely as intellectually challenging, but overwhelming in terms of workload. Legends of all night programming sessions abound both in academia and industry.

Where are the computing heroes for this generation?

“In North America, the public image of computing careers and computing professionals discourages many talented young people, especially women and minorities, from choosing to study computer science” said Princeton Dean of Engineering and Applied Sciences Maria Klawe (now President at Harvey Mudd College).[45] She elaborates: “the computing profession has been widely viewed by high school students, parents, teachers and guidance counselors as being for individuals who have been obsessed with computers since puberty and want to program sixteen hours a day. Moreover those who study computer science are often stereotyped as lacking social skills and other interests, and as working and studying in an isolated environment.”[46]

The Student Perspective

The old adage that “Those who can, do, and those who can’t, teach” is contradicted in the following recount: “David Kellam can do but he's opting to teach. He graduated from Queen's University last year with a degree in computing. But he's turning away from the tech sector as a long-term career prospect. Instead, the 23-year-old went back to Queens and enrolled in the faculty of education. ‘I see no need to get myself stuck in a grey box somewhere pounding out code that may or may not be used inside some whale of an application’ Mr. Kellam says.” [47] There are few, if any, popular cultural icons portraying the computer scientist in an unambiguously positive way, and virtually none that feature the computer scientist as the hero. In fact, the popular cartoon strip “Dilbert” immortalizes and perpetuates the standard stereotype in its main character. Dilbert is smart and is always right, but is otherwise an unappealing misfit, although some in the technology sector find him charming in a quirky sort of way. Perhaps in terms of image appeal, the computing-enabled eSciences such as Bioinformatics may appear more interesting to potential majors, and may be associated with a much more positive reputation in the eyes of today’s computationally inclined undergraduates. Ironically these disciplines actually represent far fewer career opportunities than the traditional computing career paths.

Negative Image of Computing

Changing the image of Computer Science is an important strategy with the potential to impact a wide variety of students, and it could do much to alleviate the widespread cultural ambivalence about this discipline. Although the current image of Computer Science may be not be very positive to students in general, it resonates even less with women. The need to change this image was clearly advocated by Maria Klawe, then Dean of Engineering at Princeton, in her keynote address at the 10th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, “Changing the Image of Computer Science: A North American Perspective in Conversation with Europe”.[48] She draws attention to the similarities existing between gender issues in computing in North America and corresponding tendencies displayed in most European countries, and calls for a trans-Atlantic dialogue to examine the root causes.[49] CMU’s Peter Lee observes that public perception is a very important issue: “To the general public, CS is relentlessly utilitarian and yet lacks nobility when compared with creating a chess grandmaster, finding a cure for cancer or determining the age of the universe”.[50]

Getting Rich Quick: a Thing of the Past?

Despite this cultural ambivalence, in recent years, the computing professions have drawn a large number of young people to their ranks. "In the '90s, people saw computer science as a quick opportunity for lucrative, high-paying jobs," says Stuart Zweben, chair of Ohio State University's Computer and Information-Science department. "Then companies began layoffs, and people heard about offshore outsourcing. That got them scared to go into this field. Students are becoming cautious. They have cold feet”.[51] In the past, some graduating students were lucky enough to find themselves in areas of phenomenal growth, accompanied by the enticement of good salaries, profit sharing, and strong stock incentives. Now that remuneration is more gradual and windfall riches far less frequent, students are looking to other disciplines which also may have fewer social stigmas attached. “Fears of low wages, layoffs and offshore outsourcing are driving students away, a trend that should worry anyone interested in the future of the U.S. IT industry”, Zweben says. [52]

The number of female students in computing is in a serious decline, disproportionate to the general student population

Gender Equity Issues

More than any of the other scientific and engineering disciplines, the highly competitive and confrontational culture of some Computer Science environments, which may also contain strong elements of overt gender bias, has made these much less appealing places for talented women who would otherwise flourish in this discipline. They take their talents elsewhere instead: “She got an A in Computer Science [Intro] in the fall and an A+ in Calculus [I]. And do you know what she's taking this semester? English, Psychology, and Music. (CS Faculty Member, 2000)”.[53]

The Student Perspective

The decline in students in Computer Science is clearly more serious among women

The following statistics illustrate the magnitude of these negative and dramatic trends:

- Women's share of intended CS majors decreased from 37% to 16% of SAT takers (1985-2003).
- In six baccalaureate areas between 1984-2001 women showed increases in Engineering, Physical Sciences, Mathematics, Education, and Biological/Life Sciences; only Computer Science declined.
- Women CS Baccalaureates decreased 10% from 1985 to 2001.[54]

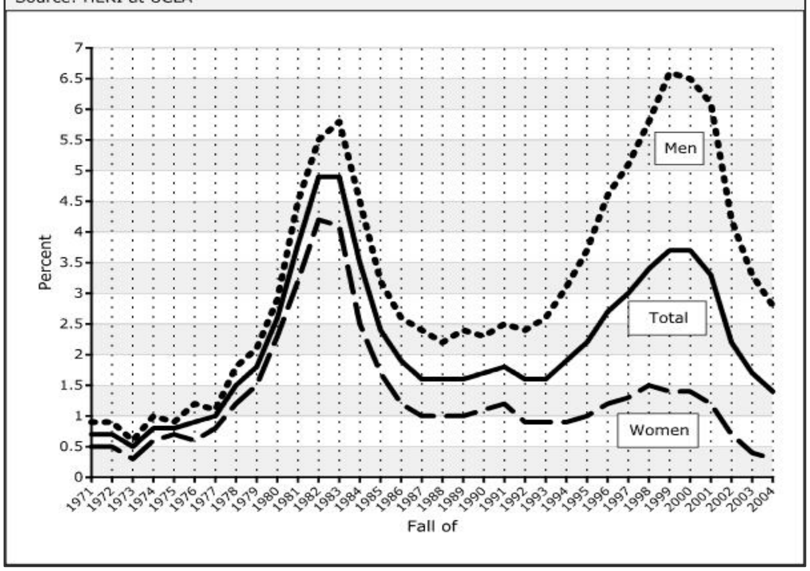
These trends continue to be tracked and reported, and vary significantly from one school to another. Many of the demographic changes in student populations vary from year to year, and are multi-determined. For instance, some women who leave Computer Science may be leaving school for reasons other than disaffection with the discipline. It must also be noted that increasing the enrollment of women at one school may not necessarily increase the *pipeline* of women entering the discipline; they merely change their choice of school to one more favorable.

Initially, Women Are Less Attracted to Computing

The poor public image of computing has already been mentioned, and although it has been observed to influence a cross-section of all students, the effect is even more pronounced among women and minorities.[55] A study from UCLA shows that interest in Computer Science as a major among both men and women grew significantly from the 1970's until the mid 1980's. This was followed by a decrease related to a general downturn in the economy, which bottomed out around 1990, and affected both men and women. After the recovery of the U.S. economy, however, the interest in Computer Science among men rebounded, but not among women. The graph illustrates several reasons why we should consider the decline in interest in Computer Science as especially severe among women.[56]

It seems that some women may have lost their previous interest in computing

Figure 1. Computer Science Listed as Probable Major Among Incoming Freshmen
Source: HERI at UCLA



Survey results from the Higher Education Research Institute at the University of California at Los Angeles show that the popularity of computer science as a major among incoming freshmen has dropped significantly in the past four years. Alarmingly, the proportion of women who considered majoring in Computer Science has fallen to levels unseen since the early 1970s. The percentage of incoming undergraduates indicating that they would major in Computer Science declined by over 60 percent between the Fall of 2000 and 2004, and is now 70 percent lower than its peak in the early 1980s.[57]

The Student Perspective

We must look at the precursors to higher education to ensure that all students are adequately prepared

Once Attracted, Women Soon Leave

A number of factors help explain this gendered attrition in Computer Science:

- Women expect focus and succeed when faculty have high expectations
- Concern about insufficient faculty increases the gender gap
- Same-sex peer support is less available in departments with a gender imbalance[58]

Lack of Encouragement and Unapproachable Faculty

These factors also contribute to attrition rates for women:

- Faculty in the average CS department mentor only 3 hours per week
- 25% mentor to overcome under-representation
- Only 23% actually initiate mentoring
- Fewer than half of faculty encourage students to persist
- Weeding-out discourages more women than men, including the talented
- Discouraging students is common [59]

Engineering Approach

Understanding of these problems is becoming more widespread, and due to the activities of NSF such as ITWT, Broadening Participation in Computing, and Gender and Science and Engineering, the emphasis is moving toward action. The National Center for Women in IT (NCWIT) seeks to identify, pilot, and spread promising and effective practices. This new approach asks what works, rather than why it works.

In the definitive "Women and Information Technology: Research on Under Representation" Joanne Cohoon and William Aspray state: "This engineering approach to creating gender balance has promise. Just as engineering has produced many benefits in the absence of complete scientific understanding (e.g., SSRI drugs, telescopes, and steam engines), the hope is that it will allow us to move toward parity before we fully understand why women are underrepresented in this and other technology fields. Instead of waiting for full knowledge of a highly complex situation, the plan is to move forward by applying what we know, experimenting and building on success." [60]

Poor Preparation in Early Grades

The role of early educational preparation cannot be ignored. Although U.S. fourth graders score well against international competition, they fall near the bottom or last by 12th grade in mathematics and science, respectively.[61] This is part of a much larger national crisis in education. Past national and state efforts to improve U.S. math and science achievement clearly demonstrate that they cannot be isolated from the need to improve the overall quality and results of the entire U.S. education system, pre-K through 16.

The need to improve our educational system is why the business community supports high-quality early childhood education, including the implementation of the No Child Left Behind Act and the Action Agenda for Improving America's High Schools, adopted at the 2005 National Education Summit on High Schools,[62] the expansion of charter schools, and greater access to and completion of higher education as well as the moral and economic imperative to address the reality that close to a third of teenagers drop out before they graduate from high school.[63]

The Agenda for Action released at the 2005 National Education Summit on High Schools[64] calls on governors as well as business and education leaders to develop a comprehensive plan for their states to restore value to the high school diploma to ensure graduates are ready for both college and work, to redesign the American high school, to give high school students the excellent teachers and principals they need, to hold high schools and colleges accountable for student success, and to streamline educational governance. The current local, state, and national focus that No Child Left Behind has brought to closing the achievement gap between majority and minority students was long overdue and is beginning to pay off.[65] Note that although "computer science" is taught in some high schools, these are really programming courses, not computer science, and also tend to be male-centric and badly taught. It is widely acknowledged across Higher Education that the best preparation for computer science is honors/AP/IB math, science, and English, *not* high school programming.

The National Perspective

A Crisis in Global Competitiveness

There has been little or no increase for research for the past 20 years

Dwindling Investment in Research

The attacks of September 11, 2001 on the World Trade Center in New York and other targets shifted national priorities dramatically: a War on Terrorism was the new, overarching focus. Although 9/11 was not the sole cause for declines in funding, this did have impact on both research & education, and resulted in an increased focus on investments in security, military and industrial sector research. Viewed long term, this nation's investment in fundamental research in the physical sciences and engineering has made almost no progress *in the past 20 years*, except in the biomedical sciences. There is a broad national failure to invest in our intellectual infrastructure.[66]

Few Resources for Computer Security

Although emphasized, security research is not sufficiently funded,[67] and it is hard to find native born computer scientists and cryptologists who can pass tight security clearances. "The concern is not that eBay will be inaccessible! Rather, the concern is that *IT systems are in the control loop of every element of the nation's critical infrastructure: the electric power grid, the air traffic control grid, the financial grid, etc. This constitutes a significant vulnerability… Less than 2% of the DHS budget is for Cyber Security"* [68]

Recruiting Difficulties in Industry

Major corporations are finding it more difficult to hire the highly trained and talented personnel they need to drive the innovation which drives the economy. While baby boomers in the computing professions begin to retire, there is also a decrease in the number of talented newcomers replacing them. The number of engineering degrees awarded in the United States is down 20 percent from the peak year of 1985.[69] In the past year, the number of newly declared computer science and computer engineering majors in the U.S.A and Canada fell 23% vs. the year before, according to the Computing Research Association.[70]

Meanwhile, Growth Abroad Accelerates

While students in the U.S. increasingly avoid Computer Science, other countries have encouraged strong and persistent growth in the engineering and computing professions. The phenomenal success of IT programs in India and their transformational effects on the Indian economy and society is legendary. Comparatively, the U.S.A grants only about 6% of the world's engineering degrees, behind China, the European Union, Japan, Russia and India, says the National Science Foundation and tech trade group AEA.[71] This leads to some startling projections:

- By 2010, if current trends continue, more than 90 percent of all scientists and engineers in the world will be living in Asia.[72]
- South Korea, with 1/6 of our population, graduates as many engineers as the U.S.[73]

Loss of Thought Leadership

While other countries do the work that has become commoditized, the U.S. is still seen as a primary source of thought leadership for the next great areas of innovation and growth, a position that will be lost if the decrease in U.S. students in these fields is not addressed soon. Edward Lazowska, CS chair at the University of Washington, and David A. Patterson, CS chair at Berkeley declare: "Given the importance of IT in enabling the new economy and in opening new areas of scientific discovery, we simply cannot afford to cede leadership. Where will the next generation of groundbreaking innovations in IT arise? Where will the Turing Awardees 30 years hence reside? Given current trends, the answers to both questions will likely be *not in the United States*. " [74]

Immigrants No Longer Fill the Gap

While competition from abroad discourages students in the U.S., immigration difficulties discourage foreign students from applying to study in the U.S. This affects undergraduate, graduate, and research programs. Enrollments have not declined as precipitously as for undergraduates, but that may change. Many U.S. graduate programs rely on foreign students: in the U.S. and Canada, 43% of CS and engineering recipients are non-resident aliens, CRA says.[75] New security regulations might keep these students from applying. In India, the number of students taking the Graduate Record Exam, required for most applicants to U.S. graduate schools, fell 56% this school year, vs. last, test administrators say. In China, the number of students taking the Graduate Record Exam fell 52%.[76]

Solutions & Strategies

Each component of this impending crisis has its own origin and scope, requiring simultaneous efforts in a number of directions and at different levels. Some of these problems have already been publicized by leading academics working through a number of organizations and collaborating with concerned industrial partners to address pieces of the problem. Clearly, a total solution depends on the cooperative efforts of all stakeholders in the outcome of Computing Education, including Industry, Academia, Government, non-governmental consortia, and the media as well as the general public.

Academic Innovation and Awareness at the National Level

Focusing on Seven Audiences

Current prevailing and widely accepted views about computing education in the United States have been reinforced by pessimistic beliefs, incomplete information, and in some cases, completely erroneous assumptions. Informed cooperation, driven by common interest across a number of domains is required to reverse these dangerous trends. This can be achieved through several means, focusing on several audiences:

- **Industry** Although many companies in the computing as well as other sectors are aware of these pipeline problems, a concerted effort must be made so that all sectors speak with one voice to effect the necessary changes.
- **The Public** Heightened awareness is needed among the general public about the critical erosion of leadership in computing technology and computing education.
- **Government Leaders** Political Leaders must focus on the impending crisis and the urgency of reversing current trends through strong legislative and policy solutions, affecting both research and education.
- **Students** It is essential to disseminate accurate knowledge about the computing professions to potential computing majors.
- **Teachers** The next generation of compelling curriculum must be created now to increase the immediacy and relevance of computing education to students.
- **Women and Other Minorities** It is absolutely imperative that proven practices be adopted immediately by universities across the nation to strongly encourage women and other minorities to this field and to retain them.
- **Immigration Policy Makers:** Reformed immigration rules and procedures must be instituted to be both pipeline-friendly *and* safe.

Expanding the Conversation

Increasing Overall Public Awareness

Many intelligent and otherwise well-informed members of the general public are simply not aware of these facts and issues. Broad awareness can be achieved by drawing attention to this subject through compelling stories carried by mass media. Leaders from Academia and Industry can take advantage of their high visibility by emphasizing the crisis nature of these trends whenever opportunity arises. This must happen first in the industrial and academic communities, and is already underway. The conversation must be broadened for distribution by popular media.

Articulating Urgency

The public can respond in a well-aligned way when the dangers of ignoring these issues are clear. Some startling facts available today may focus attention on the results of unchanged current trends such as the following warning signs.[77]

- Foreign competition: China not only graduates four times as many engineers as the United States, but it also offers lucrative tax breaks to attract companies to conduct research and development (R&D) in the country.[78]
- Interest in engineering: Out of the 1.1 million high school seniors in the United States who took a college entrance exam in 2002, just under 6 percent indicated plans to pursue a degree in engineering — nearly a 33 percent decrease in interest from the previous decade.[79]
- Student achievement: On a recent international assessment of 15-year-olds' math problem-solving skills, the U.S. had the smallest percentage of top performers and the largest percentage of low performers compared to the other participating developed countries. This is not surprising when nearly 70 percent of middle school students are assigned to teachers who have neither a major nor certification in mathematics.[80]
- Investment in basic research: In the United States, since 1970, funding for basic research in the physical sciences has declined by half (from 0.093 percent to 0.046 percent) as a percentage of the gross domestic product (GDP).[81]

Solutions & Strategies

Compelling Arguments the General Public Needs to Hear

- Innovation in the computing disciplines drives national competitiveness.
- Despite rapidly growing opportunity, students are increasingly avoiding these areas.
- If unchecked, economic decline & loss of technological leadership will result.
- Citizens must begin to advocate policy change and encourage student participation.

The Need for a National Initiative

This message must be delivered Initially by Leaders from Academia and Industry. Not since the "race for space" started when the Soviet Union launched their first satellite in 1957 has the U.S. faced a similar challenge to its leadership, which then resulted in a national obsession with educating scientists and engineers in order to reach the moon before the Soviets. However, as Thomas L. Friedman notes, "…the generation of scientists and engineers who were motivated by the threat of Sputnik and the inspiration of JFK are reaching their retirement years." [82]

Affecting Leadership at the Highest Levels

For this issue to become part of the national agenda, government leaders and legislators must understand the magnitude of the danger resulting from underinvestment in computing education and research, and act as quickly as possible through focused efforts. Leaders from industry can reinforce the urgency by highlighting the increased recruiting difficulties they are experiencing.

Compelling Arguments that the Political Leadership Needs to Hear

The first three essential points are the same as for the general public. The fourth concentrates on the need for dynamic leadership to effect change.

- Innovation in the computing disciplines drives national competitiveness.
- Despite rapidly growing opportunity, students are increasingly avoiding these areas.
- If unchecked, the results will be economic decline & loss of technological leadership.
- Leaders can avert this crisis by focusing the nation on the need for cooperative action, and by instituting programs and initiatives that will reverse these trends.

Delivering Clear Recommendations

A consortium of 15 national organizations, including ASEE, the Council on Competitiveness, and the U.S. Chamber of Commerce have issued a call to action highlighting the urgency of the crisis, advocating specific goals to remedy the situation in "Tapping America's Potential." They have clearly outlined what is needed: "Double the number of science, technology and mathematics graduates by 2015." [83] They explain why education reform is necessary but insufficient by itself.[84]

"Our organizations feel strongly that the United States must respond to this challenge as energetically as we did to the Soviet Union's launching of Sputnik in the 1950s. To remain the technological leader in the 21st century, we must establish and achieve an ambitious goal: We must double today's science, technology, engineering and mathematics graduates with bachelor's degrees by 2015. Current federal education reform programs, such as No Child Left Behind, and state efforts to redesign high schools provide a foundation that we can build on. However, to sustain American competitiveness in science and engineering, we need a focused, long-term, comprehensive initiative by the public and private sectors to:

- Build public support to make improvement in science, technology, engineering and mathematics performance a national priority.
- Motivate U.S. students and adults, using a variety of incentives, to study and enter science, technology, engineering, and mathematics careers, with a special effort targeting those in currently underrepresented groups.
- Upgrade K–12 mathematics and science teaching to foster higher student achievement, including differentiated pay scales for mathematics & science teachers.
- Reform visa and immigration policies to enable the U.S. to attract and retain the best and brightest science, technology, math and engineering students from around the world to study for advanced degrees, and to stay and work in the United States.
- Boost and sustain funding for basic research, especially in the physical sciences and engineering.

Getting The Story Straight

Driven by Leaders from Academia, Industry and National Consortia

The recommendations above, and the statement, "Tapping America's Potential: The Education for Innovation Initiative," that follows echo the alarm expressed by numerous prestigious public and private groups about the need to inspire, recruit and train a larger domestic pool of technical talent. This is so vital for the security and continued prosperity of our country that we can no longer delay action. We are calling on business leaders to unite with government officials at all levels, national, state, and local, to create the momentum needed to achieve this goal." [85]

Getting Accurate Information to Students

It is important to communicate accurately to students what these disciplines are really all about, and what kinds of activities and work they entail. Some of this needs to be driven by educators themselves. "Leaders of computer-science programs, having ridden a rising tide of employment and prominence for decades, concede they need to do a better job promoting their discipline and highlighting the great challenges ahead." [86]

Knowledge about Computing Professions

Concerned faculty sometimes invite students to informal sessions over pizza, introducing an overview of the subject areas and answering questions about what they really can do with computing. Mark Stehlik, assistant dean of undergraduate education at Carnegie Mellon's School of CS, notes that in real life, criminologists rely heavily on computers to solve crimes, something represented on TV shows by images of fingerprints quickly flashing by on a PC monitor. "What's really happening here is pattern matching. That's computer science," says Stehlik, "On these shows, we see the test-tube side; there's a computer-science side, too, that's not played up...As a field, computer science has done a lot less PR than it needs to do." [87]

Inform & Inspire

To make sure students are getting the right information about computing, the University of Washington hosts the "Why Choose CSE?" site with videos of students explaining what a day in the life of recent graduates is like, the exciting work they are doing, and why they have the "Power to Change the World". This is a good example of the efforts educators can make to inform potential majors about opportunities that exist in the field. See the site at: http://www.cs.washington.edu/WhyCSE .

Knowledge about Strong Opportunity

Providing correct data is an obvious first step in changing erroneous perceptions. Students need evidence of a strong and growing job demand, to counter the prevailing opinions that jobs are evaporating, or have all migrated elsewhere. "It's natural for people to look at a narrow point of time and conclude that businesses aren't well capitalized and jobs aren't plentiful," says Stuart Zweben, chair of Ohio State University's computer- and information-science department. "They're wrong on both counts. You've got to believe IT is an important factor in our future." Indeed, over the next decade, the Bureau of Labor Statistics sees the need for an additional 307,000 computer-software engineers, 184,000 systems analysts, 106,000 network-systems and data-communications analysts, and 103,000 managers.[88] Moreover, students need to hear specific justifications for making the effort to obtain a CS degree over, say, a degree in another discipline, answering questions such as:

- What in fact does a CS degree qualify you for?
- What qualifications do you need for an IT professional job?
- Where is the demand today, and where will it be?
- What industries can you work in as an IT professional?

Anticipated Growth May Be Greater than Many Realize

The table on the next page addresses the first three questions. The outlook for specific computing occupations is decidedly upbeat: a CS degree is a qualification for a number of interesting job possibilities. Computer and Mathematical occupations are listed below from the Occupational Outlook Handbook, using the Standard Occupational Classification (SOC) System. Data from multiple sources comprise the "Occupational Employment Projections to 2012" report submitted by the Bureau of Labor Statistics (February, 2004).[89] Also, the Science and Technology Indicators report points out that "the number of jobs requiring science and engineering skills in the U.S. labor force is growing almost 5 percent per year. In comparison, the rest of the labor force is growing at just over 1 percent." [90]

Increases in Employment May Also Be Rapid

In the following tables, the rate of anticipated growth is categorized. These projections should assuage student fears of diminishing opportunity, especially since growth will be faster than in other areas. Table 2 from the Occupational Outlook Handbook[91] highlights the 10 fastest-growing occupations overall, suggesting high growth in multiple IT occupations. Additionally, two of the IT categories in this list typically require a CS/CE degree.

Correct Information about Opportunities

What in fact does a CS degree qualify you for? What qualifications do you need for an IT professional job? Where is the demand today, and where will it be? The following data is from the Dept. of Labor Statistics. Trends are difficult to predict accurately, but these projections are quite promising.

Table 1

Growth in Computing Professions – Employment Projections to 2012				
Occupations	Typical Qualifications	2002 Employed*	Est 2012 Employed	% Change
Computer/Information Systems Mgrs	Experience as Computer Systems Analyst; BS; MBA preferred; technical emphasis	284,415	387,023	36.1
Computer & Information Scientists, Research	PhD	23,244	30,205	29.9
Computer Programmers	BS, some CS, Mathematics, Information Systems	498,597	571,303	14.6
Computer Software Engineers, Applications	BS in CS, CE, or Computer Information Systems	394,076	573,437	45.5
Computer Software Engineers, Systems	BS in CS, CE, or Computer Information Systems	181,103	408,906	45.5
Computer Support Specialists	Some require BS, some in CS or Information Systems	506,877	660,309	30.3
Computer Systems Analysts	Often: BS, in CS, Information Science, or MIS	468,345	652,691	39.4
Database Administrators	Often: BS in CS, CE, Information Science, MIS, MBA (IS concentration)	109,954	158,567	44.2
Network/Computer System Administrators	Often: BS in CS, CE, Information Science, MIS, MBA (IS concentration)	251,375	345,273	37.4
Network/Data Communication Analysts	Often: BS in CS, CE, Information Science, MIS, MBA (IS concentration)	185,971	292,044	57.0
Actuaries	No CS…			
Mathematicians	No CS…			
Operations Research Analysts	MS in Operations Research, CS, Eng; BS : CS, quantitative discipline	61,736	65,588	6.2
Statisticians	Strong background in CS	19,991	20,947	4.6

* Includes self-employed workers.

Correct Information about Growth and Rewards

In addition to their promising growth potential, these jobs actually pay quite well relative to other professions, as shown in the tables below.[92] Inaccurate perceptions about pay scale in these fields are contradicted by the Bureau of Labor Statistics, which clearly shows that computing ranks 3rd by wage of *all* occupations. Although generous stock options and legends of overnight millionaires are no longer as common, providing students correct information about actual wage standards should help encourage them to seriously consider career choices in computing. The fact that the computing professions rank third in wages overall, and rank only sixteenth in the number of people employed, at a tune when demand is increasing in this industry should provide a clear message to students that opportunity is alive and well in these fields.

Table 2

The 10 fastest growing occupations, 2002-2012 (1000's of jobs)

Occupation	Employment		Change		Most significant education or training**
	2002	2012	#	%	
Medical assistants	365	579	15	59	Moderate OTJT
Network and data communications analysts	186	292	106	57	Bachelor's degree
Physician assistants	63	94	31	49	Bachelor's degree
Social and human service assistants	305	454	149	49	Moderate OTJT
Home health aides	580	859	279	48	On-the-job-training
Medical records and health info. technicians	147	216	69	47	Associate degree
Physical therapist aides	37	54	17	46	On-the-job-training
Computer software engineers, applications	394	573	179	46	Bachelor's degree
SW engineers in computing, also in systems	281	409	128	45	Bachelor's degree
Physical therapist assistants	50	73	22	45	Associate degree

** An occupation is placed into one of 11 categories that best describes the education or training needed by most workers to become fully qualified. For more information about the categories, see Chapter II, "Selected Occupational Data, 2000 and Projected 2010" in Occupational Projections and Training Data, Bulletin 2542 (Bureau of Labor Statistics, January 2002), pp. 18-19, or in Bulletin 2572, the forthcoming 2004-05 edition of this publication.

Employment and Wages, All Occupations, 2002

Occupation	Wage	Number Employed	Number Employed (rank)
Management	$85,530	6,200,940	8
Legal	$79,910	958,520	21
Computer and Mathematical	$65,510	2,915,300	16
Architecture and Engineering	$61,750	2,372,770	17
Healthcare Practitioners and Technical	$57,310	6,359,380	7
Business and Financial Operations	$56,380	5,131,840	11
Life, Physical, and Social Science	$55,920	1,131,390	20
Arts, Design, Entertainment, Sports, and Media	$43,710	1,595,710	19
Education, Training, and Library	$42,080	7,891,810	6
Construction and Extraction	$37,520	6,170,410	9
Installation, Maintenance, and Repair	$37,220	5,215,390	10
Community and Social Services	$36,440	1,673,740	18
Protective Service	$34,840	3,006,100	15
Sales and Related	$32,210	13,507,840	2
Production	$29,280	10,128,200	4
Office and Administrative Support:	$29,020	22,649,080	1
Transportation and Material Moving	$27,880	9,581,320	5
Healthcare Support	$23,220	3,271,350	13
Personal Care and Service	$21,800	3,099,550	14
Building and Grounds Cleaning and Maintenance	$21,490	4,300,440	12
Farming, Fishing, and Forestry	$20,310	458,850	22
Food Preparation and Serving	$17,530	10,507,390	3

Creating Compelling Educational Models

Driven by Academia, Industry and Educational Consortia

Increasing Relevance

Anything that can be done to encourage early hands-on application of concepts and principles can do much to stem the tide of students leaving computing disciplines before they have had a chance to experience the relevance of the concepts being taught. Topics and courses on Gaming, Robotics, and Computer Security have immediacy and currently attract student interest. Developing and expanding curriculum into new areas with high relevancy, visibility, and value holds hope for increasing interest in Computer Science as a major.

Industry and Academia Collaboration

Microsoft is helping with efforts to invigorate the curriculum by collaborating with leading academics in these areas to issue Requests for Proposals (RFPs), focusing on developing new curriculum that is relevant, based on sound principles and related to technical topics that need to be covered. Microsoft Research hosts a Curriculum Repository that provides over 1000 curricular assets free to academics and is has most recently funded nearly 100 projects in innovative curriculum, including Robotics, Gaming, Trustworthy Computing, Mobility, Embedded Systems, and eScience as well as other areas. This collection also includes more than a dozen projects devoted to technology-enabled instruction, which harnesses some of the latest technologies including Tablet PCs to drive the next generation of technical pedagogy. It also contains coursework focusing on a gender friendly way to approach the teaching of computing.[93]

Not Just Fun and Games

There is growing evidence that attempts to increase relevance can be effective. Randy Pauch, a professor of Human Computer Interaction and Computer Science at Carnegie Mellon University, has created Alice, a system that enables college students to learn computer programming more easily. The programs produced from these efforts are 3D movies and games. Using tangible results has been formally shown to improve learning and retention, and this approach is also known to motivate students. The results are summarized in the following table.[94]

	CS1 Grade	Take CS2?
No Alice Class prior to CS1	C	47%
Alice Class Prior to CS1	B	88%

The Alice system is provided free of charge by Carnegie Mellon to other educational institutions, and is already in use at a growing number of them (24 at most recent count). One of these, Virginia Tech, now uses Alice for all 1,300 freshmen in the School of Engineering. There is a growing body of evidence supporting claims of progress. In their 2005 study “Teaching Software Engineering through Game Design”, Kajal and Mark Claypool show similar advantages for this approach tracked through 6 different measures, as illustrated in the following table.[95]

	Traditional SE	Game-Enhanced SE
Enrollment	7	22
Drop-outs	2	1
Average GPA	3.14	3.45
A’s	2	12
B’s	4	8
C’s	1	2

Taking out the Tedium

Complex concepts do not need to be studied in a vacuum. They are much less boring and difficult, both to acquire and to retain when coupled with practice. As Wayne Brookes points out in "Computing with Relevance", principles handled in a vacuum are often seen by students as irrelevant[96]. However, principles and practice need not be mutually exclusive, nor should they be. For example, John C. Knight, a professor of Computer Science at the University of Virginia, has been using Robotics to teach Advanced Software Engineering Development Methods for more than ten years, deftly combining the principles with their application.

A Problem-Solving Approach

As seen earlier, Hamilton found that adopting a problem-based model better supports student learning of computing theory.[97] Reports from John Knight's experience support this idea and suggest that students acquire theoretical concepts especially well, and retain the principles of major topics more effectively, when they have the opportunity to apply them to solving tangible problems. In his course, in addition to learning the theory behind what they create, students learn the real challenges of multidisciplinary collaboration, master the difficult skills required to integrate multiple system components, and discover first hand how to manage challenging team dynamics though hands-on experience.

Student teams from Knight's course have created their own successful companies after graduation and often cite this course as the most important and influential of their undergraduate careers.[98] These and other efforts at combining principles and practice promise similar advantages for departments adopting these approaches.[99]

Computing Combined with Another Discipline

CS majors are now more often acquiring minors in other disciplines to prepare themselves for the next wave of employment opportunities, and academic institutions are hopeful about the prospects of this approach. Carnegie Mellon now actually *requires* a minor for undergraduate computer science[100] majors and this multidisciplinary approach is receiving more emphasis.

Indiana University has approached the idea of creating computing professionals with broad competency by restructuring, consolidating, and re-chartering their computing programs into the Indiana University School of Informatics, in which they require students to study computing and one other discipline. Interestingly, this does not dilute the traditional computing disciplines. Students who wish to focus on core traditional computing areas such as algorithms may major in Computer Science and minor in Computer Science as well.[101]

They believe there is great need and opportunity for professionals trained in state-of-the-art information technology and science with an emphasis on creative human applications, and an urgent need in society for graduates with education and experience in informatics, particularly with interdisciplinary skills. The School of Informatics will graduate professionals with *both* formal preparation in information technology and subject area expertise. To this end, they are developing an innovative and successful new curriculum for information technology and its applications, as well as educating students who might not traditionally consider an educational path in technology, especially women and minorities. They also mean to encourage interdisciplinary research projects in the field of informatics, focusing on distributed systems technology, information theory and information management, human factors and human-computer interaction, and to study of the social impacts of information technology.[102]

Socially Relevant Computing

Eric Hoover reports that in the annual national survey of incoming freshman, two out of three freshmen say it is essential or very important to help others who are in difficulty, the highest percentage in a quarter century.[103] This information, gathered as part of the Cooperative Institutional Research Project conducted by the Higher Education Research Institute at UCLA, shows that a record number of students – 83 percent – say they volunteered at least occasionally during their senior year of high school.[104]

Creating Compelling Education Models

Slightly more men than women said making more money was a "very important" factor in attending college and choosing a particular college (73.5 percent to 69 percent). More women than men said a top reason was to "learn more about things that interest me" (81.4 percent to 73.1 percent).[105]

Clearly an opportunity exists for institutions of higher learning to challenge students to apply their enthusiasm toward viable avenues for applied computation that will benefit the greater good. It is easy to see how some of these solutions cut across multiple problems, including those of attraction, retention, gender equity, and relevancy and even affect debates about whether teaching theory first is advantageous or not. This is also reinforced by Peter Lee's observation that there is a dearth of "grand challenges" being presented to new students.[106]

Driven by Academic Institutions, Educational Consortia

Government Involvement Amplifies Industry Efforts

Although Industry can, and should, invest in these and other specific, high-value programs in collaboration with Academia, these contributions cannot begin to replace the governmental resources that could be made available. Collaborations between Industry and Academia are best leveraged when coupled with greater national educational initiatives in Research and Learning.

Why These Are No Longer a Mystery

Encouraging Practices that Encourage Women

Obviously, since women comprise more than ½ of the general population, anything that addresses their gross underrepresentation in computing can do much to affect pipeline issues overall in a positive way. We are now aware that the lack of participation by women is a problem that is solvable through fairly straightforward and relatively inexpensive changes in policy and emphasis. There is a growing body of practices that enable computing programs to effectively achieve gender-proportionate enrollments. For instance, at Carnegie Mellon the proportion of female undergraduates in the CS program rose from 7 percent to 42 percent[107] between 1995 and 2000, after the program implemented a focus on specific areas of improvement.

Six Things That Made a Difference at CMU

- *Addressing the Experience Gap* between men and women starting in computing helped by providing four different ways to enter the program.[108]
- *Reforming Admission Policies* to de-emphasize preference for students with prior experience makes sense, since prior experience does not predict eventual success.[109]
- *Paying More Attention to Good Teaching* especially in the early courses.[110]
- *Contextualizing Computer Science* with curriculum placing technology in the context of its real-world uses and impact, increased relevance and appeal.[111]
- *Culture Changes* were enabled by influencing student perceptions of computing through the efforts of teaching faculty most in contact with first-year students.[112]
- *Outreach to High Schools* greatly influenced talented students applying to computing programs, more than doubling their number during this project.[113]

Effective Yet Inexpensive to Implement

As we have seen, gender bias in computing education results from a number of factors, predominantly a lack of same-sex peer support, insufficient mentoring, little encouragement to persist, insufficient faculty, unclear work expectations, and blatant discouragement by faculty, which can be remedied by applying proven and effective practices to create more supportive environments. These practices are embraced in a few places in Academia but not all, and their adoption should become standard. The budgetary impact, if any, is negligible. Merely supplying these missing elements in practice and procedure promises to be a fruitful approach.

Five Achievable Changes that Promise Real Results [114]

- Ensure that all students receive clear work expectations.
- Provide opportunities for same-sex peer support for women.
- Support and encourage same-sex faculty mentoring for women.
- Advocate and reward active mentoring by all faculty for all students
- Encourage talented students to persist to forestall early discouragement.

What Is Good for the Goose Is Good for the Gander

Note that the value provided to female students by these practices is valuable to all students and may help contribute to a decline in attrition rates among men as well. Simply put, helping women will also increase the numbers of men who enter and persist in computing programs. Similarly, encouraging the participation of other minorities underrepresented in computing may be achieved by a similar introduction of easy-to-implement practices.

Benefits for National Security

A very specific type of shortage would be alleviated by proportional inclusion of women and other underrepresented minorities in computing, specifically for security-related work. Even if immigration policies improved dramatically, security clearance for some sensitive work cannot be assigned to foreign-born nationals. An increase in the availability of qualified computer scientists emerging from the ranks of U.S. born women and other minorities would greatly alleviate this situation, as expressed in the Government University Industry Research Roundtable discussions held at the National Academy of Science in Washington, D.C. in 2004.[115]

Improved Immigration Policies

Leading Academics and Educational Organizations must make it clear to legislators and other government leaders that policies need to be changed to be flexible yet secure, lest current practices contribute more to defeat national progress than terrorists themselves could ever hope to accomplish. The situation is already critical. The decline in the numbers of foreign students entering U.S. schools to study in the computing disciplines has been accelerated by the tightening of immigration policies since the attacks of 9/11. Unfortunately, these stringent policies exclude many people who should be allowed to study at U.S. institutions in the attempt to keep out dangerous individuals who should be kept from entering the country for security reasons. If this does not change soon, the tendency for talented students from abroad to go elsewhere may become permanent.

Immigration Reforms are Critical

Recommendations are clear for changes in the current self-defeating efforts in managing the movement of foreign nationals. We must reform visa and immigration policies to enable the U.S. to attract and retain the best and brightest science, technology, math, and engineering students from around the world to study for undergraduate and advanced degrees and to stay to work in the United States.[116] To achieve this we must:

- Provide an expedited process to obtain permanent residence for foreign students who receive advanced degrees in these fields at U.S. universities. *(Federal)* [117]
- Ensure a timely process for foreign students who want to study science, technology, engineering and math fields at U.S. universities to obtain the necessary visas by clearing Department of Homeland Security requirements. *(Federal)* [118]

Recommendations

Awareness and Advocacy at the National Level

Awareness is Rising Among the Elite, But Not Yet Widespread

Leaders in Industry, Academia, and various organizations such as ABET, ASEE, ACM, NAE are engaged in serious dialogues over these issues, and in some cases are beginning to create a modest amount of change in certain areas, including the reform of some school curricula. However, the conversation still does not include the general public. Public discourse is essential for driving the consensus needed to result in significant change. People need to be motivated to write to their congressmen and congresswomen to demand legislation that will reverse these trends, but they cannot do so until they know the facts and understand the issues. Political leaders listen to concerns from the general public, especially when the trends are significant and undeniable. However, the public still believes that there is no opportunity in computing, that all the jobs have gone away to other regions, or are soon to leave, and that the rewards in these professions are in sharp decline, despite facts to the contrary.

Public and Political Determination is Critical

Academia, Industry and Political Leaders Must Work Together

While they are effective and articulate spokesmen in their areas of expertise, few industry and academic leaders have the widespread name recognition required to be effective advocates for change. Even those who are well-known cannot create change alone. It is therefore important that captains of industry and academia band together with influential political leaders of all persuasions to achieve a critical mass and create a forum that cannot be ignored. It is essential that loss of technological leadership is recognized as the most important disaster to defend against, rather than destruction by terrorists. While military preparedness is important, the inability to compete in a truly global marketplace is potentially far more crippling than individual attacks by extremists. Widespread prosperity creates conditions in which terrorism is much less sustainable. However, lack of determination to excel in technology and innovation, is suicidal in a world where most other nations recognize these as the most essential goals.

Specific Programs Must Be Enacted Soon

Refocusing and Clarifying Student Awareness

A concerted campaign must be mounted to reinvigorate the interest of young people in the United States in computing as a profession. Previous public campaigns against the dangers of smoking and drunk driving have been highly effective in changing attitudes and behaviors in the general public. So there must be a campaign articulating the dangers of technological ignorance for the public at large. More specifically there should be a campaign to give students across the nation accurate and authoritative data on the "upside" of computing as a profession, including the wages, benefits, growth, and robustness of the field domestically. Otherwise, students have little incentive to pursue such a challenging course of study.

Changing Practices in Academia

Academics have the power to institute reforms that have clearly been shown to improve attraction and retention of the best and brightest to the computing disciplines. The means to achieve specific goals are now quite clear, based on studies, research and successful experiments as well as pilot programs. We now have a good idea about what changes greatly increase the attraction of talent to the field, and help to retain talented students once they become involved in computing fields. These include, but are not limited to:

- Teaching computational theory in context.
- Combating stereotypes with accurate data about the computing professions
- Instituting educational practices that work for women and minorities, as well as for men.
- Teaching by using tangible outcomes, for instance, offering courses in robotics and gaming.
- Further testing of the idea of computing-plus-a-minor as a way to compete by being more versatile.
- Highlighting opportunities to apply computing in socially relevant ways.

Implications

Awareness and Determination

Clearly, loss of thought leadership is not inevitable, since workable solutions are known. The issue is really awareness and determination. There is now widespread awareness in academic and industry circles of these issues. Academia and Industry are motivated, are closest to the issues, and may have the most to lose by inaction. For change to occur, these issues must be more widely acknowledged, and must become part of a focused and public national agenda connected to real programs that change trends by instituting proven practices.

Systemic, Interlocking Issues

Incremental improvements can be achieved through more enlightened practices at a local level, but it is obvious that widespread *systemic* changes are needed at the national level for true reversal of these multi-determined trends. Problems in the higher education pipeline, for instance, cannot fully be addressed until insufficiencies at the K-12 levels are fixed. The supply of graduate students for research will remain inadequate as long as immigration policies focus on keeping the wrong people out without also encouraging the right people to enter and contribute. The investment and entrepreneurial environment must also be reinvigorated to encourage innovation at home rather than abroad.

Broad Focus Is Required

This report was originally intended to focus closely on the dwindling supply of computer science talent in the U.S., the implications for industrial hiring and national competitiveness, and the possible educational remedies. However, these problems are symptomatic of a much broader set of issues, all of which must be addressed for change to be successful. Resolution of this set of problems requires determined and coordinated attention not merely focusing on Computer Science in higher education, but also on education in all the physical sciences and engineering, as well as on the related cultural, social, and political dynamics which impact this field.

Specifics on Globalization

The Job Migration Task Force of ACM has published a report on a two year study of these problems which is definitive in its treatment and recommendations.[119] The study clearly points out that to stay competitive in a global IT environment and industry, countries must adopt policies that foster innovation and improve their ability to attract, educate, and retain the best IT talent. Educational policy and investment is at the core. The study outlines specifies effective educational measures all countries can take to respond to off shoring:

1. Evolve computing curriculum at a pace that embraces the changing nature of IT.
2. Ensure that computing curriculum prepares students for the global economy.
3. Teach students to be innovative and creative.
4. Evolve curriculum to balance between foundational knowledge of computing, and business and application domain knowledge.
5. Invest in good technology, curriculum, and teachers for the educational system. [120]

Another Comprehensive Set of Recommendations

The Augustine Report from the National Academies, "Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future" provides such an approach by addressing the entire set of interlocking problems, and should be advocated widely and adopted broadly as a definitive roadmap for collective action.[121] Summarized in the following section, it contains powerful, specific recommendations calling for extensive improvements in four areas:

- <u>Elementary Education</u>: K-12 Science & Mathematics
- <u>Research</u> : In Science & Engineering
- <u>Higher Education</u>: In Science & Engineering
- <u>The Environment of Innovation</u>: Support for Innovation and Investment

The value of this report lies not only in its broad scope and completeness, but also in its prescription for detailed solutions with specific recommendations and suggested target numbers. In addition to clearly identifying the essential components of the problem, the report focuses on remedies ranging across all sectors; academic, industrial, and governmental.

Augustine Report Recommendations *(summary)*

10,000 Teachers, 10 Million Minds and K–12 Science and Mathematics Education	
Recommendation A	Increase America's talent pool by vastly improving K–12 science and mathematics education.
Action A-1:	**Annually recruit 10,000 science and mathematics teachers** by awarding 4-year scholarships and thereby educating 10 million minds.
Action A-2:	**Strengthen the skills of 250,000 teachers** through training and education programs at summer institutes, in master's programs, and Advanced Placement and International Baccalaureate (AP and IB) training programs and thus inspire students every day.
Action A-3:	**Enlarge the pipeline by increasing the number of students who take AP and IB science and mathematics courses.**
Sowing the Seeds through Science and Engineering Research	
Recommendation B	Sustain and strengthen the nation's traditional commitment to long-term basic research to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.
Action B-1:	**Increase the federal investment in long-term basic research by 10%** a year over the next 7 years.
Action B-2:	**Provide new research grants of $500,000 each annually**, payable over 5 years, to 200 of the most outstanding early-career researchers.
Action B-3:	**Institute a National Coordination Office for Research Infrastructure** to manage a centralized research-infrastructure fund of $500 million per year over the next 5 years.
Action B-4:	**Allocate at least 8% of the budgets of federal research agencies to discretionary funding.**
Action B-5:	**Create an Advanced Research Projects Agency-Energy (ARPA-E)** organization in the Department of Energy (DOE) similar to the Defense Advanced Research Projects Agency (DARPA).
Action B-6:	**Institute a Presidential Innovation Award** to stimulate scientific and engineering advances in the national interest.
Best and Brightest in Science and Engineering Higher Education	
Recommendation C	Make the U.S. the most attractive setting in which to study and perform research so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from within the U.S. and throughout the world.
Action C-1:	**Increase the number and proportion of U.S. citizens who earn physical-sciences, life-sciences, engineering, and mathematics bachelor's degrees** by providing 25,000 new 4-year competitive undergraduate scholarships each year to U.S. citizens attending U.S. institutions.
Action C-2:	**Increase the number of U.S. citizens pursuing graduate study in "areas of national need" by funding 5,000 new graduate fellowships each year.**
Action C-3:	**Provide a federal tax credit to encourage employers to make continuing education available** either internally or though colleges and universities to their scientists and engineers.
Action C-4:	**Continue to improve visa processing** for international students and scholars.
Action C-5:	**Provide a 1-year automatic visa extension** to international students who receive doctorates or the equivalent in science, technology, engineering, mathematics, or other fields of national need at qualified U.S. institutions to allow them to remain in the U. S. and seek employment. If these students are offered jobs by U. S. employers and pass a security screening test, they should be provided automatic work permits and expedited residence status.
Action C-6:	**Institute a new skills-based, preferential immigration option.**
Action C-7:	**Reform the current system of "deemed exports".**
Incentives for Innovation and the Investment Environment	
Recommendation D	Ensure that the U.S. is the premier place in the world to innovate; invest in downstream activities such as manufacturing and marketing; and create high-paying jobs that are based on innovation by modernizing the patent system, realigning tax policies to encourage innovation, and ensuring affordable broadband access.
Action D-1:	**Enhance intellectual-property protection** for the 21st century global economy.
Action D-2:	**Enact a stronger research and development tax credit** to encourage private investment in innovation.
Action D-3:	**Provide tax incentives for innovation in the U. S.**
Action D-4:	**Ensure ubiquitous broadband Internet access.**

Solution Scope

How to Do Everything Needed?

Although the Augustine Report does address the complete set of problems, the fact remains that *all* of these issues need to be covered. Their size and complexity make it impossible for any one entity to address them in their entirety. Each sector should focus on the areas with which they are most concerned and for which they may possess the best assets. For instance, Microsoft Corporation has a long standing interest in education and its outcomes, as do many other technology companies, and acts on this interest by focusing on particular areas in which it can best contribute to ensuring a continuous supply of high quality, talented computing professionals.

Example: Higher Education Outreach

Microsoft engages with Higher Education on a number of different levels, focusing on very specific research collaborations and university outreach programs though the External Research & Programs and University Relations groups in the Microsoft Research division. These programs concentrate on extending the state of the art in computing and related disciplines, investing by means of RFPs and other grants in a number of research areas of particular interest, and by connecting with key investigators at leading research institutions. They also encourage innovative curriculum and teaching technologies, and advocate policy change where needed. The collaboration interest areas include Computational Sciences, Trustworthy Computing, Gaming in Education, Robotics, Sensor Networks, Digital Inclusion, Bioinformatics, and the use of Tablet PCs to improve education. Significant long-term activities are underway to positively influence the number and quality of graduates applying for jobs in the computing disciplines, the value of which is obvious to Microsoft and indeed to all technology companies.

Example: K-12 Outreach

Microsoft also provides grants worldwide to programs, especially toward computing-related curriculum, through several initiatives.

Innovative Teachers

This is a program that connects with the global community of educators, enhancing teaching by providing resources to teachers to bring 21st Century information and communications technology advantages into the classroom. This will help educators to transform the way they teach and learn, foster creativity, encourage teamwork, and engage students. Free, high quality classroom instructional content, professional development, and access to technology resources are provided to help teachers integrate technology throughout the learning process.[122]

U.S. Partners in Learning

Microsoft provides resources including people, partnerships, services, philanthropy, and products to empower students and teachers addressing the Digital Inclusion issues facing education today by facilitating access to technology and training. Working with state and local education communities, U.S. Partners in Learning is making significant investments of both money and personnel to help build sustainable models for using technology to meet local education needs, and to advance innovative teaching and learning, and is guided by national and local advisory groups.[123]

Conclusion

A National Problem with International Implications

Although the examples of industry outreach listed here indicate some investments that Microsoft is making in education, research, and policy, a variety of other companies have their own versions of programs which play to their special areas of focus and strengths. However, industry is but one segment that must be mobilized. Leaders in academia, legislators, educational consortia, and the media all have roles to play in elevating this topic to the level of a national dialog, albeit with far-reaching international ramifications.

Indeed, the problems outlined in this discussion are no longer solely the worry of the United States and other developed nations, but are now being acknowledged worldwide to varying degrees. The global impact of these efforts is critical for innovation as it affects the supply of the best and brightest available for the computing, physical sciences, and engineering fields. It has especially strong implications for the computing professions which enable other advanced research and learning in these disciplines. How any nation responds to these challenges ultimately determines the degree to which it will remain competitive in a global marketplace increasingly driven by technology and innovation.

End Notes

1 Friedman, T. L. The Flat World. Breakfast Series Presentation, Redmond, Washington, August 30, 2005.

2 Steve Lohr, quoted in “Computer Science Majors--and More”. CNET, Aug 22, 2005. http://news.com.com/Computer+science+majors--and+more/2100-1022_3-5841842.html

3 Vegso, Jay. (May 2005). Interest in CS as a Major Drops among Incoming Freshmen. Computing Research Association, Volume 17/Number 3.

4 Ibid.

5 Ibid.

6 Ibid.

7 Ibid.

8 National Science Board. Science and Engineering Indicators. 2004

9 Ibid.

10 U.S. Dept of Labor, Bureau of Labor Statistics. Computer Software Engineers, Applications: Employment and Wages 2002, http://www.bls.gov/home.htm. See also the section: Computer Software Engineers, Applications: Employment and Wages, 2002

11 Ibid.

12 Hoover, Eric. Freshman Survey: More Students Plan to Lend a Hand. The Journal of Higher Education, February 3, 2006, pp. A40-A43.

13 Ibid.

14 Ibid.

15 Ibid.

16 National Science Board, *Science and Engineering Indicators, 2004*. Volume 2, Appendix Table 2–34.

17 Ibid.

18 http://www.coe.unt.edu/PDF/NationalDefenseinEducationFinal-rev.pdf

19 Prediction by Richard E. Smalley “Nanotechnology, the S&T Workforce, Energy, and Prosperity,” presentation to the President’s Council of Advisors on Science and Technology (PCAST), March 3, 2003.

20 Kessler, Michelle. Fewer College Students Choose Computer Majors. U.S.A Today, August 8, 2004.

21 Ibid.

22 Jane Margolis and Fisher, Allan. Unlocking the Clubhouse: Women in Computing, page 129. MIT Press, 2002.

23 Ibid.

24 Chabrow, E. Computer-Science Enrollments Down At U.S. Universities. http://outsourcingpipeline.com, August 16, 2004

25 Ibid.

26 Friedman, T. L. “Bush Disarms, Unilaterally” New York Times, April 15, 2005

27 Top Media Stories of 2001. At http://www.iwantmedia.com/topmediastories2001.html. January 2, 2002.

28 El Akkad, O. Where Jobs Are and Students Aren't. http://theglobeandmail.com September 21, 2005.

29 Steve Lohr, quoted in “Computer Science Majors--and More”. CNET Aug 22 2005. http://news.com.com/Computer+science+majors--and+more/2100-1022_3-5841842.html

30 Geewax, M. Offshoring Growing Faster Than Thought. Palm Beach Post. May 18, 2004

31 Friedman, T. L. The Flat World. Breakfast Series Presentation, Redmond, Washington, August 30, 2005.

32 Friedman, T. L. The World is Flat: A Brief History of the Twenty-First Century. Thomson Gale, 2005.

33 Ibid.

34 Ibid.

35 John Sargent, Senior Policy Analyst, U.S. Department of Commerce, presented to the Computing Research Association, 2/2004.

36 Lee, Peter. “CS Pipeline”, presentation to Computer Science Faculty, July 7, 2004. https://www.wiki.cs.cmu.edu/public/pmwiki.php?pagename=Main.ArticlesAboutTheCSPipeline

37 Ibid.

38 Ibid.

39 Lazowska, Edward. Personal communication, December 13, 2005

40 Brookes, W. Computing with Relevance. Copyright c_2004, Australian Computer Society, Inc. Conferences in Research and Practice in Information Technology, Vol. 30. Raymond Lister and Alison Young, Eds. Reproduction for academic, not-for profit purposes permitted provided this text is included.

41 Hamilton, M., Harland, J. & Padgham, L. (2003), Experiences in teaching computing theory via aspects of problem-based learning, *in* T. Greening & R. Lister, eds, 'Proc. Fifth Australasian Computing Education Conference (ACE2003), Adelaide, Australia', number 20 *in* 'Conferences in Research and Practice in Information Technology', Australian Computer Society, pp. 207–211.

42 Brookes, W. Computing with Relevance. Copyright c_2004, Australian Computer Society, Inc. Conferences in Research and Practice in Information Technology, Vol. 30. Raymond Lister and Alison Young, Eds. Reproduction for academic, not-for profit purposes permitted provided this text is included.

43 Ibid.

44 Chabrow, Eric. Computer-Science Enrollments Down At U.S. Universities. http://outsourcingpipeline.com, Aug 16,2004

45 Klawe, M. Changing the Image of Computer Science: A North American perspective in Conversation with Europe. Keynote address at ITiCSE '05, June 27-29, Monte de Caparica, Portugal. ACM 1-59593-024/8/05/0006.

46 Ibid.

47 El Akkad, O. Where Jobs Are and Students Aren't. http://theglobeandmail.com September 21, 2005.

48 Klawe, M. Changing the Image of Computer Science: A North American perspective in Conversation with Europe. Keynote address at ITiCSE '05, June 27-29, Monte de Caparica, Portugal. ACM 1-59593-024/8/05/0006.

49 Ibid.

50 Lee, Peter. "CS Pipeline", presentation to Computer Science Faculty, July 7, 2004. https://www.wiki.cs.cmu.edu/public/pmwiki.php?pagename=Main.ArticlesAboutTheCSPipeline

51 Zweben, Stuart, quoted in Chabrow, Eric. Computer-Science Enrollments Down At U.S. Universities. http://outsourcingpipeline.com, Aug 16,2004

52 Ibid.

53 J. McGrath Cohoon. Minimizing the Risk of Losing Women from a Male-Dominated Discipline. Research findings presentation, September 2003

54 Ibid.

55 Klawe, M. Changing the Image of Computer Science: A North American perspective in Conversation with Europe. Keynote address at ITiCSE '05, June 27-29, Monte de Caparica, Portugal. ACM 1-59593-024/8/05/0006.

56 Vegso, Jay. (May 2005). Interest in CS as a Major Drops among Incoming Freshmen. Computing Research Association, Volume 17/Number 3.

57 Higher Education Research Institute. http://gseis.ucla.edu/heri

58 J. McGrath Cohoon. Minimizing the Risk of Losing Women from a Male-Dominated Discipline. Research findings presentation, September 2003

59 Ibid.

60 J. McGrath Cohoon and William Aspray. Women and Information Technology: Research on Underrepresentation. MIT Press, 2006, pp. 471-472.

61 U.S. Department of Education, National Center for Education Statistics, *Trends in International Mathematics and Science Study.*

62 Available at http://www.achieve.org/achieve.nsf/2005Summit?OpenForm and http://www.nga.org

63 Jay P. Greene and Marcus Winters, Public High School Graduation and College Readiness Rates: 1991–2002 (New York: Manhattan Institute for Policy Research, February 2005); Christopher B. Swanson, Who Graduates? Who Doesn't? A Statistical Portrait of Public High School Graduation, Class of 2001(Washington, DC: Urban Institute, 2004); Andrew Sum, Paul Harrington et al., The Hidden Crisis in the High School Dropout Problems of Young Adults in the U.S.: Recent Trends in Overall School Dropout Rates and Gender Differences in Dropout Behavior (Washington, DC: Business Roundtable, February 2003). See: http://www.businessroundtable.org

64 Available at http://www.achieve.org/achieve.nsf/2005Summit?OpenForm and http://www.nga.org

65 The National Assessment of Educational Progress (NAEP) long-term trend assessment scores released on July 14, 2005, show gains among 9-year-olds in reading, as well as a closing of the achievement gap in reading for African American and Hispanic students. The NAEP data also show significant improvement and a closing of the achievement gap in mathematics among 9- and 13-year-olds.

66 http://www.cra.org/govaffairs/blog/archives/trendsinBasicResearch_byAgency.001.html

67 PITAC update presentation, Ed Lazowska, Computer Science & Engineering Chair, University of Washington; Co-Chair, President's Information Technology Advisory Committee.

68 Ibid.

69 Ibid. Appendix Table 2-22.

70 Kessler, Michelle. Fewer College Students Choose Computer Majors. U.S.A Today, August 8, 2004.

71 Ibid.

72 Prediction by Richard E. Smalley "Nanotechnology, the S&T Workforce, Energy, and Prosperity," presentation to the President's Council of Advisors on Science and Technology (PCAST), March 3, 2003.

73 National Science Board, *Science and Engineering Indicators, 2004.* Volume 2, Appendix Table 2–34.

74 Lazowska, E.D., and Patterson, D.A. Computing Research: A Looming Crisis. ACM SIGCOMM address

75 Kessler, Michelle. Fewer College Students Choose Computer Majors. U.S.A Today, August 8, 2004

76 Ibid.

77 The Business Roundtable. Tapping America's Potential: the Education for Innovation Initiative. www.businessroundtable.org/pdf/20050727002TAPStatement.pdf

78 Ibid.

79 Ibid.

80 Ibid.

81 Ibid.

82 Friedman, T. L. The World is Flat: A Brief History of the Twenty-First Century. Thomson Gale, 2005.

83 The Business Roundtable. Tapping America's Potential: the Education for Innovation Initiative. www.businessroundtable.org/pdf/20050727002TAPStatement.pdf

84 Ibid.

85 Ibid.

86 Chabrow, Eric Computer-Science Enrollments Down At U.S. Universities. http://outsourcingpipeline.com, Aug 16, 2004.

87 Ibid.

88 Ibid.

89 U.S. Dept of Labor, Bureau of Labor Statistics. Computer Software Engineers, Applications: Employment and Wages, 2004, http://www.bls.gov/home.htm.

90 National Science Board. Science and Engineering Indicators. 2004

91 Ibid.

92 U.S. Dept of Labor, Bureau of Labor Statistics. Computer Software Engineers, Applications: Employment and Wages, 2002, http://www.bls.gov/home.htm. See also the section: Computer Software Engineers, Applications: Employment and Wages, 2002

93 See http://www.msdnaa.net/curriculum/repository.aspx

94 Pausch, R. Alice Tea Party. SIGCSE 2005 Presentation. http://www.alice.org/SIGCSE_Tea_Party_2005.htm

95 Claypoool, K, and Claypool, M. Teaching Software Engineering through Game Design. 10th Annual SIGCSE Conference on Technology in Computer Science Education. June 27-29, 2005. Monte de Caparica, Portugal.

96 Brookes, W. Computing with Relevance. Copyright c_2004, Australian Computer Society, Inc. Conferences in Research and Practice in Information Technology, Vol. 30. Raymond Lister and Alison Young, Eds. Reproduction for academic, not-for-profit purposes permitted provided this text is included.

97 Hamilton, M., Harland, J. & Padgham, L. (2003), Experiences in teaching computing theory via aspects of problem-based learning, *in* T. Greening & R. Lister, eds, 'Proc. Fifth Australasian Computing Education Conference (ACE2003), Adelaide, Australia', number 20 *in* 'Conferences in Research and Practice in Information Technology',

Australian Computer Society, pp. 207–211.

98 Knight, J. C. Personal Communication, June, 1994.

99 Ibid.

100 See CMU undergrad requirements at http://www.csd.cs.cmu.edu/education/bscs/

101 Groth, Dennis. Personal communication, March, 2006.

102 http://www.informatics.indiana.edu/overview/mission.asp

103 Hoover, Eric. "Freshman Survey: more Students Plan to Lend a Hand," in The Chronicle of the Journal of Higher Education, February 3, 2006, pp. A16-A19.

104 Ibid.

105 Hoover, Eric. "Freshman Survey: more Students Plan to Lend a Hand," in The Chronicle of the Journal of Higher Education, February 3, 2006, pp. A16-A19.

106 Lee, Peter. "CS Pipeline", presentation to Computer Science Faculty, July 7, 2004.

107 Jane Margolis and Fisher, Allan. Unlocking the Clubhouse: Women in Computing, page 129. MIT Press, 2002.

108 Ibid. page 130.

109 Ibid. pp 130-131.

110 Ibid. page 131

111 Ibid. pp 131-133.

112 Ibid. pp 133-134.

113 Ibid. Page 134.

114 J. McGrath Cohoon. Minimizing the Risk of Losing Women from a Male-Dominated Discipline. Research findings presentation, September 2003

115 Educational Paradigms for Homeland Security, GUIRR, in the 2004 report at http://www7.nationalacademies.org/guirr/GUIRR_Annual_Reports.html and in discussion at the Globalization, Competitiveness and Workforce Roundtable Meeting, February 3-4, 2004, Washington, D.C.

116 The Business Roundtable. Tapping America's Potential: the Education for Innovation Initiative. www.businessroundtable.org/pdf/20050727002TAPStatement.pdf

117 Ibid.

118 Ibid.

119 William Aspray, Frank Mayadas, Moshe Y. Vardi, Editors. Globalization and Offshoring of Software. A Report of the ACM Job Migration Task Force, ACM, 2006 http://www.acm.org/globalizationreport/

120 Ibid.

121 See the Executive Summary at: http://www.nap.edu/execsumm_pdf/11463.pdf

122 http://www.microsoft.com/education/InnovativeTeachers

123 http://www.microsoft.com/education/PartnersinLearning.mspx