CRA COMPUTING LEADERSHIP SUMMIT 2005

Melrose Hotel, 2430 Pennsylvania Avenue, NW
Washington, DC - 202-955-6400
February 28, 2005

AGENDA

Sunday, February 27

7:00PM-11:00PM	Hospitality Room (***William Tell Room***)

Monday, February 28 — ***Room: Potomac III***

8:00AM	Continental Breakfast
8:30AM	Welcome, why are we here, critical questions we want to answer, process (***Jim Foley***, CRA chair).
8:40AM	The Current Situation *(**Ed Lazowska***, PITAC co-chair and CRA gov't affairs co-chair).
8:55AM	Overview of what all our participants are already doing in both areas (***Andy Bernat**,* CRA).
9:15AM	Break into small groups to brainstorm on action items. Goal is to identify actionable items, such as those illustrated in the statement of purpose. Each group deals with one of the two following topics:

1. Federal Investment in Computing Research and Human Resources for Research

   - Computing research funding is inflation-adjusted flat or going down. Why does this matter to the nation as a whole (rather than to just us)? That is, what is the case we can make for increased funding—on the Hill, to the White House, to influentials? What are the missed opportunities? What are the most compelling concrete data?
   - What specific actions can we take to refine and make the case?
   - What is the best case we can make to federal agencies that have traditionally funded CS research, e.g., DARPA and NSF? To other agencies—DOE, NIH, NASA, DHS, non-DARPA DOD—to whom we can argue computing is foundational to their interests?
   - What specific actions should we take in refining and making the case to the agencies?

   Discussion Group Leaders: ***Al Spector, Jeff Vitter, Bill Wulf***

2. Human Resources Pipeline

- At the high-school level—how develop/what are the messages and specific actions to:
  - **--** Bring more of the best and brightest into computing?
  - **--** Attract more students overall?
  - **--** Determine with whom to communicate—students, parents, teachers?
- In college, how develop/what are the messages and specific actions to:
  - **--** Attract undeclared freshmen majors, and retain declared majors?
- In college, how develop/what are the messages and specific actions to:
  - **--** Convince the best and brightest to go on to grad school?
  - **--** Understand what holds them back?

Discussion Group Leaders: ***Carl Chang, Rick Rashid, Bobby Schnabel***

10:30AM Each discussion group reports out to entire group.

11:00AM **Break**

11:30AM Topic Leaders present coalesced lists of actions on Topic 1 and Topic 2 to entire group; group assigns priorities to actions. Action groups and discussion leaders identified for lunch-time and after-lunch planning on high-priority action items.

1. Research Funding: ***Jeannette Wing*** (co-chair of CSTB and Professor, CMU School of CS)
2. Human Resources: ***Maria Klawe*** (Princeton University Dean of Engineering and ACM Past President)

12:30PM **Lunch** at tables organized around high-priority actions; discussion continues after lunch. Each action group identifies an Action Leader to report out and be the point person for making the action happen. Each group identifies two-month, six-month, and one-year goals.

2:15PM Reports from Action Leaders on two-month, six-month, and one-year goals and how they will coordinate to keep the ball rolling. Reports and discussion moderated by Topic Leaders—***Maria Klawe, Jeannette Wing***.

3:10PM Wrap-up, discussion re desired ways to continue the coordination processes and discussion that got started here today. (Options include do nothing explicit, do this every year, do it every year in a modified form, do it twice a year—with Snowbird one of the times, off-Snowbird years some other venue. The July 2005 CRA Board meeting in Vancouver can be a venue for this group or any subgroups that want to meet then.) (***Jim Foley***)

3:30PM Adjourn to reception with CRA board and local guests (***William Tell Room***)

CRA Computing Leadership Summit
Organized by the Computing Research Association

Melrose Hotel, Washington, DC—February 28, 2005

Attendees

AAAI
Ron Brachman, President
Carol Hamilton, Executive Director
Tim Finin, CRA Board Representative

ACM
David Patterson, President
Maria Klawe, Past President
John White, Executive Director
Barbara Simons, Past President
Cameron Wilson, Director, Public Policy Office
Eugene Spafford, CRA Board Representative
Jennifer Rexford, CRA Board Representative

CACS/AIC (Canadian Assoc. of Computer Science/ Assoc. d'informatique canadienne)
Gord McCalla, President
Frank Tompa, CRA Board Representative

IEEE-Computer Society
Carl Chang, 2004 President
Anne Marie Kelly, Associate Executive Director
Oscar Garcia, CRA Board Representative
Guylaine M. Pollock, CRA Board Representative

SIAM
Martin Golubitsky, President
Jim Crowley, Executive Director
Mel Ciment, SIAM Government Affairs
Joel M. Widder, Lewis-Burke Associates LLC
Bobby Schnabel, CRA Board Representative

USENIX
Michael Jones, President
Rob Kolstad, SAGE Executive Director
Ellie Young, Executive Director

CSTB (Computer Science and Telecommunications Board, NRC)
Jeannette Wing, Co-Chair
Charles Brownstein, Executive Director

CRA
Jim Foley, Chair
Dan Reed, Chair-Elect
Jan Cuny, Vice Chair
Andy Bernat, Executive Director
Peter Harsha, Government Affairs Director
John King, Chair, Gov. Affairs Committee
Jeff Vitter, Co-Chair, Gov. Affairs Committee

PITAC
Ed Lazowska, PITAC Co-Chair (and Co-Chair, CRA Gov't Affrs. Comm.)

ECEDHA (Electrical and Computer Engineering Department Heads Association)
Robert Janowiak, Executive Director
Wayne Bennett **(**also CRA Gov't Affrs. Comm.)

Industry Representatives
Alan Eustace, **Google**
Wayne Johnson, **HP**
Al Spector, **IBM**
T.V. Lakshman, **Lucent Bell Labs**
Rick Rashid, **Microsoft**
Steve Heller, **SUN**
Rick White, **TECHnet**

Other Organizations
Nick Belkin, **ASIST (**American Society for Information Science and Technology)
Sue Fratkin, **CASC** (Coalition for Advanced Scientific Computation)
Craig Stewart, **CASC**
Robert Kahn, **CNRI** (Corporation for National Research Initiatives)
Chad Evans, **Council on Competitiveness**
William Wulf, **National Academy of Engineering**
Lucy Sanders, **NCWIT (**National Center for Women and Information Technology)
Peter Freeman, **NSF/CISE** (National Science Foundation, Computer & Information Science & Engineering Dir.)

CRA COMPUTING LEADERSHIP SUMMIT 2005

Melrose Hotel, Washington, DC
February 28, 2005

PURPOSE

The summit is being convened in response to three major difficulties facing the computing community:

1. Decreased US federal funding for computing research.
2. The small number of US and Canadian citizens who attend graduate school in computing and related fields.
3. The small number of high school students and college freshmen who choose computing and related fields as their major.

Our purpose is to identify actions that can be taken either by our individual organizations or jointly by one or more of the organizations, and to establish communications and collaborations that will help us carry out those actions. The actions are likely to include expanding our cooperation on activities currently underway, as well as identifying completely new activities. Actions that have already been suggested include:

- Joint political action on the part of all the societies and the major companies. This might take the form of an executive fly-in to meet with the President and OMB Director and congressional leaders; it might involve placing ads in *The Washington Post* and *Wall Street Journal* or similar newspapers; or it might be conducting a congressional briefing.
- Work with our friends on the Hill to set up congressional hearings on research funding as a way to highlight the issues.
- Member societies might publish the same article, co-signed by all society presidents, in our flagship publications. Article conveys seriousness to our members; calls them to action.
- Help student chapters of our societies to conduct programs on "why go to grad school" for juniors.
- Help agencies, such as NIH, that have a great need for more computing capabilities; find ways to invest more in computing research.
- Hold Grand Challenges workshops to highlight important research opportunities.
- Develop data showing relation between federal investment in computing research and share of GDP and balance of payments due to US IT hardware and software and services companies and the taxes they and their employees pay.
- Make prospective Ph.D. students aware of the many career opportunities, not only in research labs and research universities, but in advanced product development and undergraduate education as well.
- Work actively to dispel the negative stereotypes surrounding computing careers.

FEBRUARY 14, 2005

ECONOMIC FUTURES
By Michael Mandel

The Budget's Misguided Parsimony

Cuts in R&D and education spending are shortsighted because they'll hurt something called MFP, a key force behind U.S. economic oomph

Today I'm going to tell you about the most important economic statistic you've never heard of. It's more significant than the trade deficit, more far-reaching than the budget gap, and even a bigger deal than the unemployment rate.

The statistic is multifactor productivity (MFP), and it comes out every year or so in a Bureau of Labor Statistics report called, quite naturally, "Multifactor Productivity Trends." The latest report, which showed that MFP rose by 2% in 2002, was released on Feb. 1 and received virtually no coverage in the press.

The biggest increase since 1992, this gain is the main reason the U.S. economy has continued to prosper despite the big budget and trade deficits. The lack of attention is especially unfortunate given the upcoming debates over the Bush Administration's budget proposal for 2006, which cuts funding for education as well as nondefense research and development -- two of the key factors driving MFP.

FREE MONEY. Of course, right now you're asking: What the heck is multifactor productivity, and why is it so important? MFP is the lesser-known cousin of labor productivity, which is the amount of output that an average worker can produce in an hour. So, for example, if you're digging ditches, your labor productivity is the number of feet of ditches you can dig in an hour.

A rise in labor productivity can happen for a lot of different reasons. Workers can have more and better machinery and equipment to use -- say, a backhoe rather than a shovel, to move dirt. Or the workers can become better trained in using the equipment they already have. In either case, the increase in labor productivity carries a cost: the price of the backhoe or the expense of training the worker.

Multifactor productivity measures something different. When MFP rises, it means output per hour of the average worker goes up without any additional skills or education or a change in equipment. An increase in MFP equals free money, extra production that you don't have pay for.

MEASURE OF STRENGTH. Multifactor productivity is borne of the essence of technological innovation -- the creation of new products and new opportunities out of ideas and thin air. For example, the spread of the Internet has not only made doing business easier and cheaper but also allowed people to do things that weren't even possible in the past. Think about Amazon (**AMZN**), Google (**GOOG**), and eBay (**EBAY**). Wireless phones aren't just a substitute for landlines; they enable people to organize their activities in very different ways.

The rate of multifactor productivity growth represents the single best indicator of the economy's true strength. When MFP is increasing rapidly, the size of the economic pie expands, real wages rise, profits go up, and everyone feels good. When that figure stagnates, things are tough all around.

For example, multifactor productivity didn't rise at all in 1973-83, a period that included the era of runaway inflation, President Jimmy Carter's famous "malaise" speech, and the deepest recession since the Great Depression. During that stretch, the stock market, adjusted for inflation, fell by 34%, while real hourly wages for production and nonsupervisory workers descended by 11%.

NECESSARY FUNDING. By contrast, the birth of the New Economy can be clearly seen in the sharp acceleration of multifactor productivity growth starting in 1996. From that point to 2002 (the latest year for which figures are available), MFP gained a bit more than 1% a year. From 1995 to today, real wages have risen by 9%, while the inflation-adjusted stock market is up by 68%.

An economy with rapid multifactor productivity growth is potentially quite profitable for investors, which helps explain why the U.S. can attract so much foreign capital to fund its trade deficit. High MFP also generates lots of extra output, useful for paying for, say, military actions or better health-care benefits. It's like having a cushion or a security blanket.

So what does this have to do with the budget debate now starting up in Washington? Higher multifactor productivity comes mainly via technological progress. And that requires the willingness to spend on R&D and education.

HARMFUL CUTBACKS. Unfortunately, in an attempt to cut the budget deficit, the Bush Administration has held down government spending on R&D and education. The budget proposal calls for federal nondefense R&D spending for fiscal year 2006 to fall by 1% compared to the previous year, after inflation, while real outlays on education and training are proposed to drop by 6%.

This misguided parsimony can only hurt the nation's ability to maintain a rapid pace of multifactor productivity growth. Putting more resources into technology and education is the best way to ensure that the bounty of higher MFP continues in the future.

Mandel is chief economist for *BusinessWeek*
Edited by Patricia O'Connell

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CISE 1994-2004: A Decade in Review

By Peter A. Freeman and Lee Harle

Computing faculty who have recently submitted proposals to CISE have come to understand the increasing demands on CISE's budget. While there has been considerable growth in the budget in recent years, this growth has not kept pace with the escalating number of promising research and education opportunities and challenges in our field. Consequently, proposal success rates in CISE are dropping to new lows. Like you, we are concerned about this. This article seeks to shed some light on CISE budget and funding trends, and a companion article on page 4, "CISE Update: Adjusting to the Increase in Proposals," describes CISE's current plan to adapt in this changing environment.

The CISE budget has grown significantly in the last decade, but most markedly over the past five years as can be seen in Figure 1. A significant change in growth rate can be observed in the 1999-2000 period. Why? In February 1999, the President's Information Technology Advisory Committee (PITAC) published a report that asserted that "Federal support for research in information technology is seriously inadequate." In response to PITAC recommendations, NSF deemed Information Technology Research (ITR) a budget priority area and, indeed, Networking and Information Technology Research and Development (NITRD) became a government-wide priority. And more dramatic increases in the CISE budget ensued. Figure 1 describes CISE budget growth over the 1994-2004 period and demonstrates that growth in CISE funding exceeded growth in NSF overall.

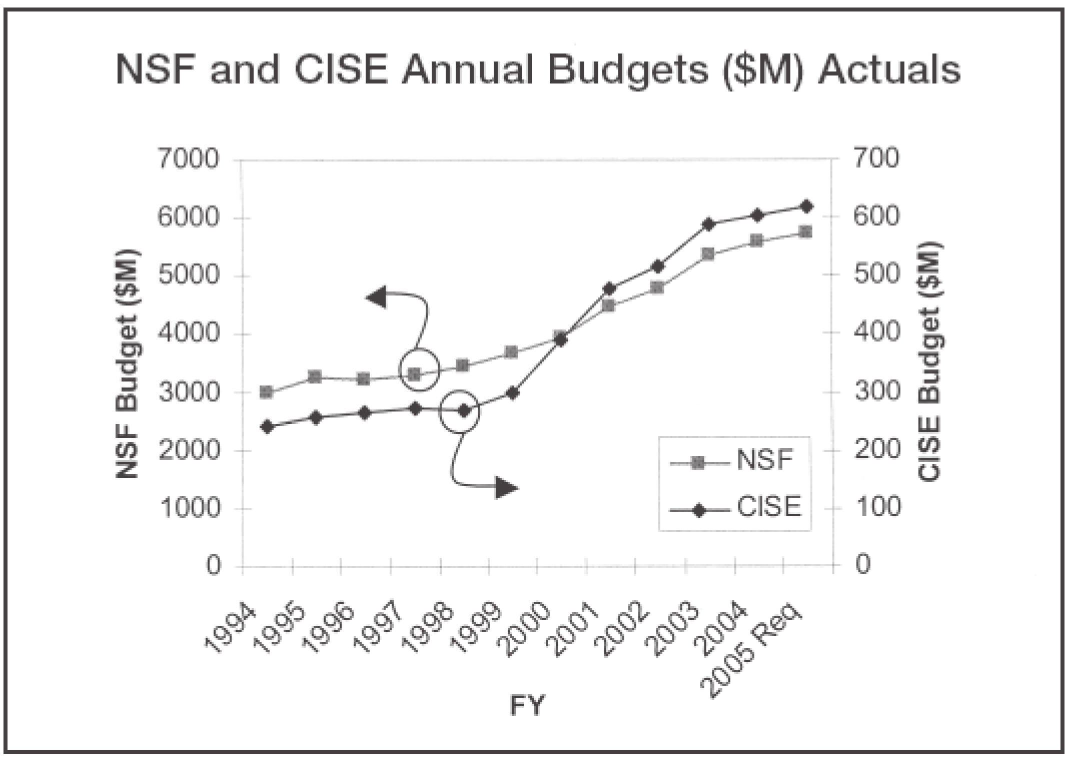

Figure 1: Comparison of NSF and CISE Annual Budget trends for 1994-2004.

Over this same time period, the number of CS and CE faculty nationally has also been rising, with CRA's Taulbee Survey indicating a greater than 35 percent increase from 1998 to 2003 in tenure-track faculty in Ph.D.-granting CS and CE departments. This increase in the number of computing faculty can be attributed to the movement of researchers to academia following the closing or downsizing of industrial labs, and to the growing number of new Ph.D.s accepting tenure-track positions in Ph.D.-granting departments in recent years.

The growing number of CS and CE faculty, coupled with NSF's annual solicitations for ITR proposals (2000-04), resulted in a significant increase in the number of proposals submitted to CISE. This growth in what we call 'proposal pressure' should not, however, be attributed only to the growing number of faculty and our ITR competitions. In fact, it is also associated with the expanding mission of our field and the associated increase in emerging research and education opportunities. Undoubtedly, there is growing recognition of the promise of computing research contributions in society, and as part of that, the expanding role of computing in science and engineering research and education in general (e.g., in science and engineering informatics).

Figure 2 compares the number of proposals received and reviewed by CISE and the number of proposals awarded, and it presents the funding rates calculated from these data over the 1994-2004 period. In 1998, CISE received a total of 2,044 competitive proposals. By 2004, this number had risen to 6,222. Figures 1 and 2 clearly indicate that while the CISE budget more than doubled between 1994 and 2004, the number of proposals received on an annual basis has more than tripled during this ten-year time period. Over the same period, the funding rate for proposals submitted to CISE has dropped considerably, from approximately 36 percent in 1994 to a decadal low of 16 percent in 2004.

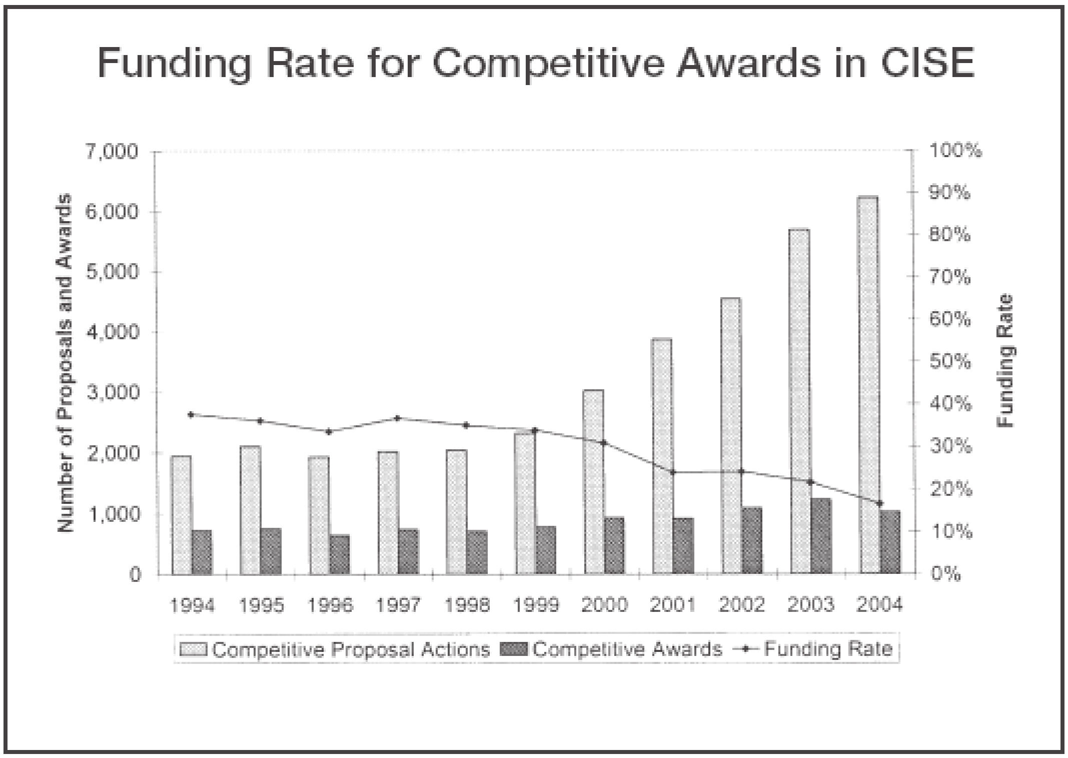

Figure 2: Competitive proposals received, proposals awarded, and successful funding rate trends for CISE, 1994-2004. Competitive proposals are initiated through the normal NSF review process in a specific fiscal year. The data do not include amendments to existing grants such as supplements.

While in the early part of the last decade CISE funding rates were higher than NSF's overall funding rate, more recently CISE funding rates have dropped below the overall rate by quite a significant margin, even while the CISE budget was growing at a faster rate, as demonstrated in Figure 3.

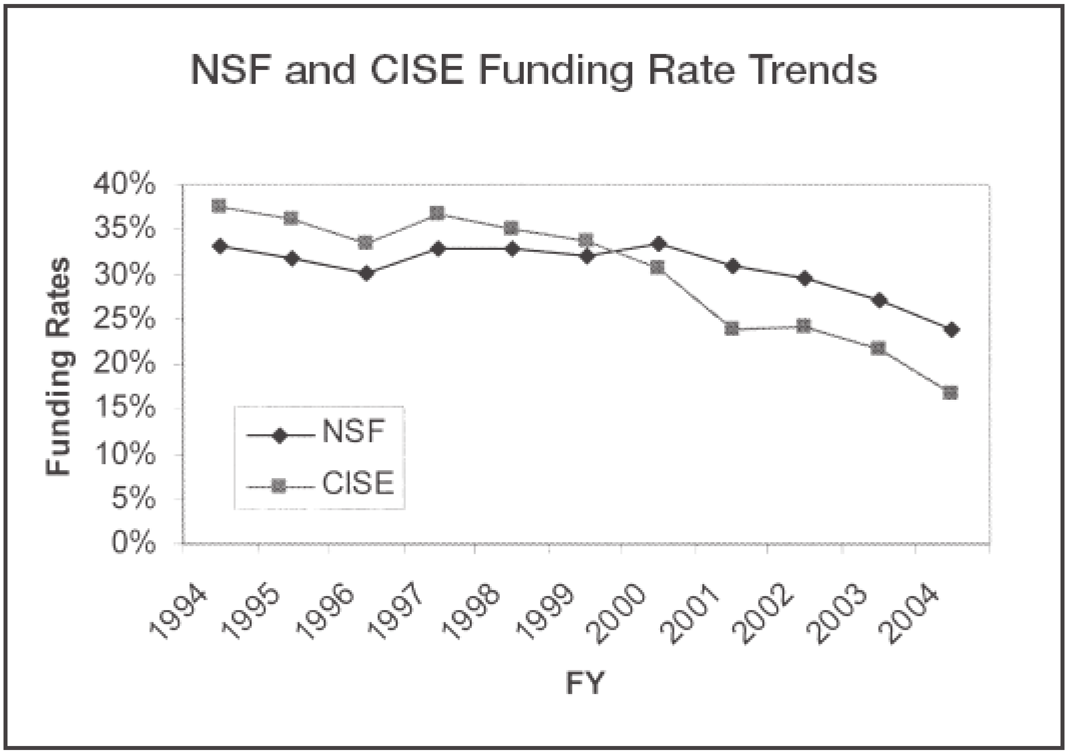

Figure 3: Comparison of NSF and CISE Funding Rates for 1994-2004.

Funding rates within CISE programs vary. However, direct comparisons across programs cannot readily be made due to different funding histories and proposal solicitation strategies. For example, some programs carry significant mortgage obligations, upwards of 60 percent of their annual budget, due to awards recommended for funding in previous years. Some programs impose restrictions on the number of proposals a PI can submit while others do not, which of course modulates funding rate data. Yet others are new programs that may be either oversubscribed or undersubscribed at their inceptions before reaching relatively steady-state conditions. What is clear, though, is that funding rates for CISE as a whole have halved in a decade.

Also contributing to the decline in funding rates is the desire to increase average grant size. As indicated in Figure 4, although award duration has remained relatively constant over the ten-year period, the average grant size has risen steadily—from an annual level of $72,000 in 1994 to an annual level of $165,000 in 2004. This growth in average grant size is consistent with NSF's goals and is responsive to PITAC's recommendations.

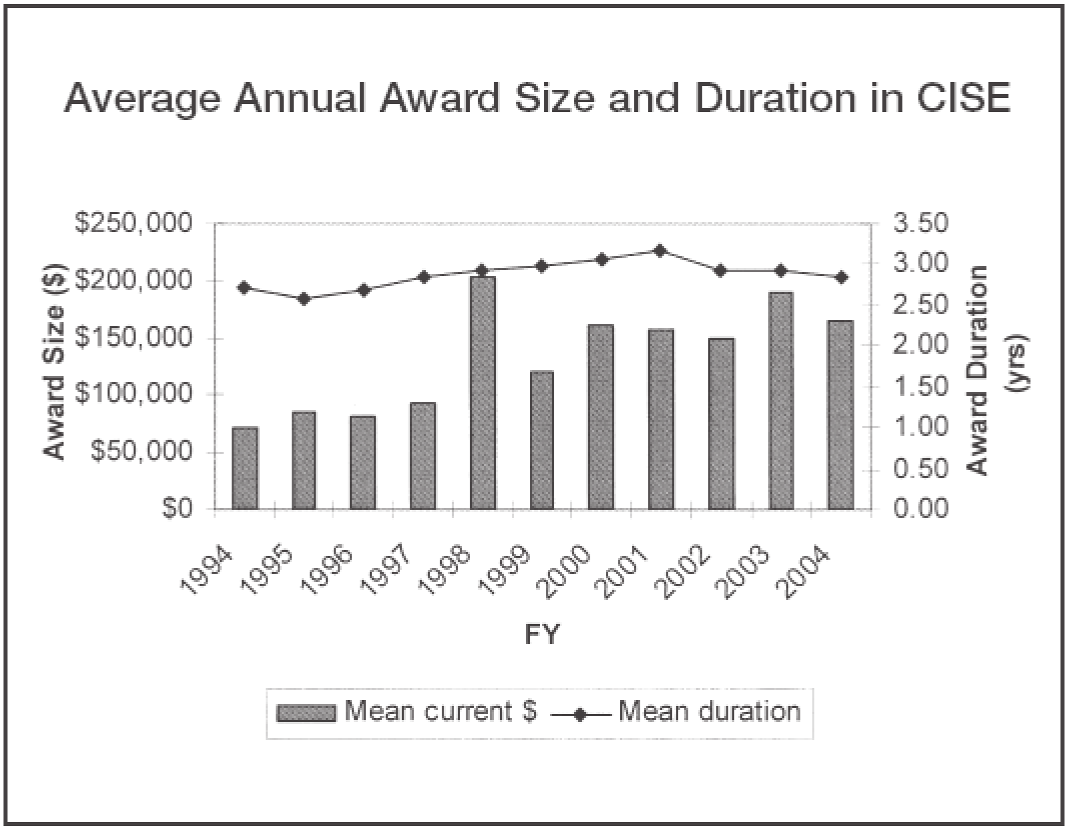

Figure 4: Average Award Size and Duration in CISE, 1994-2004.

We think you can see that a combination of a number of factors—increasing numbers of proposals, an increased number of awards, increasing average annual award amounts, and budget growth that has not kept pace with demand—has resulted in significantly reduced proposal funding rates.

The companion article, "CISE Update: Adjusting to the Increase in Proposals," describes CISE's current plan to adapt to this changing environment. However, as we make and implement these plans, the community must also think about its funding needs, priorities, and strategies. With computing advances increasingly important to advances in other science and engineering fields, computing faculty must continue to explore funding opportunities from all sources, including CISE and other organizations within NSF. Moreover, the computing research and education community needs to speak with one voice about the critical contributions that they can, and indeed must, be empowered to make towards creating a safe, healthy and vibrant civil society, both in the United States and around the world.

Peter Freeman (pfreeman [at] nsf.gov) is the Assistant Director of Computer and Information Science and Engineering at the National Science Foundation. Lee Harle is an NSF AAAS Fellow.

http://www.nae.edu/NAE/engecocom.nsf/weblinks/MKEZ-68JK55/$File/Engineering%20Research.pdf

Assessing the Capacity of the U.S. Engineering Research Enterprise

PRELIMINARY REPORT FOR PUBLIC REVIEW

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

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Executive Summary

Leadership in innovation is essential to U.S. prosperity and security. In a global, knowledge-driven economy, technological innovation, the transformation of new knowledge into products, processes, and services, is critical to competitiveness, long-term productivity growth, and the generation of wealth. Preeminence in technological innovation requires leadership in all aspects of engineering: engineering research—which bridges scientific discovery and practical applications; engineering education—which gives engineers and technologists the skills to create and exploit knowledge and technological innovation; and the engineering profession and practice—where knowledge is translated into innovative, competitive products and services.

U.S. leadership in technological innovation seems certain to be seriously eroded unless current trends are reversed. The accelerating pace of discovery and application of new technologies, investments by other nations in research and development (R&D) and the education of a technical workforce, and an increasingly competitive global economy are challenging U.S. technological leadership and with it our future prosperity and security. Although many current measures of technological leadership—percentage of gross domestic product invested in R&D, number of researchers, productivity, volume of high-technology production and exports—still favor the United States, worrisome trends are already adversely affecting the U.S. capacity for innovation. These trends include: a disciplinary skewing of the nation's research priorities away from engineering and physical sciences and toward the life sciences; continuing erosion of the engineering research infrastructure; a relative decline in the interest and aptitude of American students in engineering and other technical fields; and growing uncertainty about the our ability to attract and retain gifted science and engineering talent from abroad at a time when foreign nationals constitute a large and productive fraction of the U.S. R&D workforce.

Today more than ever the nation's prosperity and security depend on technical strengths. We will need robust capabilities in fundamental and applied engineering research to address economic, environmental, health, and security challenges and to capitalize on opportunities created by scientific discoveries by inventing new products and services, creating new industries and jobs, and generating new wealth. For instance, applying technological advances to achieving global sustainability will require significant investment, creativity, and technical competence. Advances in nanotechnologies, biotechnologies, new materials, and information and communication technologies may provide solutions to difficult environmental, health, and security challenges, but their development and application will require significant R&D and engineering efforts.

Current trends in research investment and workforce development are early warnings that the United States could fall behind other nations, both in its capacity for technological innovation and in the size, quality, and capability of its technical workforce. Unless, the United States maintains its resident capacity for technological innovation and its ability to attract the best and the brightest talent from abroad, the economic benefits of advances will not accrue to Americans. We must take action immediately to overcome existing imbalances in support for research and to address emerging critical challenges. These actions must include both changes in direction by key stakeholders in the engineering research enterprise and bold new programs designed specifically to promote U.S. technological innovation. This conclusion echoes the findings of other recent assessments by the Council on Competitiveness (2001, 2004), the President's Council of Advisors on Science and Technology (2002, 2004a,b), National Science Board (2003); National Academies (COSEPUP, 2002; NAE, 2003, 2004; NRC, 2001), and other distinguished bodies (DOE, 2003; National Commission on Mathematics and Science Teaching for the 21st Century).

The recommendations below are focused on critical changes in public- and private-sector investment priorities, programs, and activities. The section that follows proposes a new, nationwide initiative to encourage and support technological innovation.

Recommendation 1. Federal research and mission agencies should increase significantly their investments in engineering and physical sciences research, particularly long-term fundamental research, to sustain broad-based science and engineering advancement across disciplines. These agencies should also continue to encourage multidisciplinary research through support of project-specific research teams and other institutionalized mechanisms, such as engineering research centers and university-industry research centers.

Recommendation 2. Federal and state governments should invest more resources in upgrading and expanding laboratories, equipment, information technologies, and other infrastructural needs of research universities to ensure that the national capacity to conduct world-class engineering research is sufficient to address the technical challenges that lie ahead. Geographically dispersed, world-class research facilities will have the added benefit of making engineering attractive to more students (at home and from abroad), will stimulate a competition of ideas among research groups working on related problems, and will provide a basis for the emergence of networks of researchers and clusters of industry across the nation.

Recommendation 3. State and federal governments, academic institutions, accreditation bodies, and the private sector should take steps to cultivate U.S. student interest in, and aptitude for, careers in engineering, and in engineering research in particular. These steps should include providing more funding for graduate fellowships and traineeships and faculty development, as well as supporting efforts to improve K–12 math and science education to prepare high school students for careers in science and engineering.

Recommendation 4. Academic institutions, accreditation bodies, and other public and private-sector stakeholders should encourage the development and implementation of innovative curricula that address the realities of contemporary engineering practice and the needs of the nation, without compromising the teaching of fundamental engineering principles.

Recommendation 5. Immigration procedures should be addressed to enable American industry and universities to continue to attract top scientific and engineering talent from around the world.

Although the committee recognizes that many other study panels, committees, and task forces have made similar recommendations, little progress has been made toward fulfilling them.

Funding for engineering research has been flat for two decades, and the imbalance between funding for the life sciences and engineering/physical sciences has worsened. Considering the magnitude and character of the technological challenges facing us, continuing to conduct business-as-usual is simply not an option. Responding to these technological challenges and opportunities and the changing nature of global competition and technological innovation will require changes—in the way our research is prioritized, funded, and conducted; in the way we attract, educate, and train engineers and scientists; in policies and legal structures that affect related issues, such as intellectual property; and in strategies to maximize contributions from institutions engaged in technological innovation and workforce development (e.g., universities, corporate R&D laboratories, federal agencies, and national laboratories).

Of course, major undertakings in anticipation of opportunities are always difficult, but the United States has a history of rising to the occasion. At least twice before in times of great challenge and opportunity, the federal government responded creatively with novel programs that not only served the needs of society, but also reshaped institutions. Consider, for example, the Land-Grant Acts in the nineteenth century, which not only modernized American agriculture and spearheaded America's response to the industrial revolution, but also led to the creation of the great public universities that have transformed American society. Another example is the G.I. Bill and government-university research partnerships created during the 1940s, which were instrumental in establishing U.S. economic and military leadership and creating the American research university, which has sustained U.S. leadership in the production of new knowledge and the creation of human capital.

The current challenges to the nation's prosperity and national security, as well as the opportunities for global leadership, call for a bold new initiative of similar magnitude to break away from the status quo. One possible approach, very much in the spirit of the Land-Grant Acts and the recent commitment to leadership in biomedical research and practice through nation-wide investments in academic medical centers, would be to establish interdisciplinary "discovery-innovation institutes" on the campuses of American research universities. Like the agricultural experiment stations created by the Hatch Act of 1887, these institutes would be responsive to particular societal priorities and designed to stimulate technological innovation, educate a world-class high-technology workforce, and ensure U.S. economic growth. Like academic medical centers, they would bring together research, education, and practice. Like major corporate R&D laboratories, they would link fundamental scientific discoveries with the engineering research necessary to yield innovative products, services, and systems. Unlike industry laboratories, however, they would be focused on meeting long-term societal needs, as well as educating the next-generation technical workforce.

University-based discovery-innovation institutes would be funded through a partnership of federal, state, and possibly local governments, industry, foundations, and universities. Schools of engineering, management, medicine, law, and social sciences would all have a compelling interest in participating in genuinely interdisciplinary projects to address the complex challenges facing the nation. The institutes would compete for funding and would be responsible for producing both short- and long-term deliverables. They would engage both undergraduate and graduate students and would be expected to provide new curricular materials and engage in outreach activities. Because discovery-innovation institutes would be focal points of activity for participants from many disciplines and communities—faculty, students, engineers, industrial managers, legal experts, health professionals, and financial experts—they would provide a nurturing environment for entrepreneurship.

To ensure that the discovery-innovation institutes have a transformative impact, the committee believes they should be funded at a level commensurate with past federal initiatives and current investments in other areas of research, such as biomedicine and manned spaceflight. Thus, federal funding would build to a level of several billion dollars per year that would be distributed throughout the engineering research and education enterprise; comparable amounts would be invested by states, industry, foundations, and universities. The committee recognizes that federal and state budgets are severely constrained and will likely remain so for the foreseeable future. Nevertheless, as the American public comes to understand the importance of leadership in technological innovation to national economic prosperity and security, the committee believes bold initiatives of this magnitude could be given a higher priority in the federal budget process, just as funding for biomedical research was doubled in the 1990s.

Meeting the challenges facing the nation and the world will require transformational rather than incremental innovations. Challenges such as sustainable energy, global climate change, drug-resistant diseases, water management, the emergence of megacities, and broad-based economic development require multifaceted but highly coordinated solutions. The nation's best minds from multiple disciplines need the freedom and the incentive to step out of their disciplinary silos to address these challenges. Industry needs improved access to the intellectual capabilities housed in universities and better frameworks for partnering with universities in mutually beneficial ways.

Discovery-innovation institutes would provide a way of breaking through the historic constraints of university engagement with the broader innovation system. To transform the technological innovation capacity of the United States, the discovery-innovation institutes must be implemented on a national scale and backed by a strong commitment to excellence by all participants. Most of all, discovery-innovation institutes would be engines of innovation that would transform institutions, policies, and culture and enable our nation to solve critical problems and maintain leadership in the global, knowledge-driven society of the twenty-first century.

The committee puts forward the concept of discovery-innovation institutes, not as a definite prescription for federal action, but to illustrate the bold character and significant funding level we believe are necessary to secure the nation's leadership in technological innovation. Modifications of this concept or equally bold, transformative alternatives may emerge as the result of a national discussion in the engineering community. The purpose of this illustration is to stimulate and encourage that discussion.

REFERENCES

COSEPUP (Committee on Science, Engineering and Public Policy). 2002. Observations on the President's Fiscal Year 2003 Federal Science and Technology Budget. Washington, D.C.: National Academies Press.

Council on Competitiveness. 2001. Imperatives for Innovation: The Second National Innovation Summit 2001. Washington, D.C.: Council on Competitiveness. Executive summary available online at: *http://www.compete.org/pdf/summit_exsumm.pdf*.

Council on Competitiveness. 2004. Innovate America. Washington, D.C.: Council on Competitiveness. Available online at: *http://www.compete.org/pdf/NII_Final_Report.pdf*.

DOE (U.S. Department of Energy). 2003. Critical Choices: Science, Energy, and Security. Final Report of the Secretary of Energy Advisory Board Task Force on the Future of

Science Programs at the Department of Energy. Washington, D.C.: U.S. Department of Energy.
NAE (National Academy of Engineering). 2003. The Impact of Academic Research on Industrial Performance. Washington, D.C.: National Academies Press.
NAE. 2004. The Engineer of 2020: Visions of Engineering in the New Century. Washington, D.C.: National Academies Press.
National Commission on Mathematics and Science Teaching for the 21st Century. 2000. Before It's Too Late: A Report to the Nation. Jessup, Md.: Education Publications Center.
NRC (National Research Council). 2001. Trends in Federal Support of Research and Graduate Education. Washington, D.C.: National Academy Press.
NSB (National Science Board). 2003. The Science and Engineering Workforce: Realizing America's Potential. NSB 0369. Available online at: *http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf*.
PCAST (President's Committee of Advisors on Science and Technology). 2002. Assessing the U.S. R&D Investment. Available online at: *http://www.ostp.gov/PCAST/FINAL R&D REPORT WITH LETTERS.pdf*.
PCAST. 2004a. Sustaining the Nation's Innovation Ecosystem: Maintaining the Strength of our Science and Engineering Capabilities. Available online at: *http://www.ostp.gov/PCAST/FINALPCASTSECAPABILITIESPACKAGE.pdf*.
PCAST. 2004b. Sustaining the Nation's Innovation Ecosystem: Information Technology Manufacturing and Competitiveness. Available online at: *http://ostp.gov/pcast/FINALPCASTITManuf%20ReportPackage.pdf*.

THE TASK FORCE
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THE KNOWLEDGE ECONOMY:
IS THE UNITED STATES LOSING ITS COMPETITIVE EDGE?

BENCHMARKS OF OUR INNOVATION FUTURE

February 16, 2005

Agilent Technologies, ASTRA, American Chemical Society, American Electronics Association, American Mathematical Society, American Physical Society, Association of American Universities, Computing Research Association, Computing Technology Industry Association, Computing Systems Policy Project, Council on Competitiveness, Hewlett-Packard, Intel, Lucent, Materials Research Society, Microsoft, National Association of Manufacturers, NASULGC, The Science Coalition, Semiconductor Industry Association, Southeastern Universities Research Association, Texas Instruments

Introduction

For more than half a century, the United States has led the world in scientific discovery and innovation. It has been a beacon, drawing the best scientists to its educational institutions, industries and laboratories from around the globe. However, in today's rapidly evolving competitive world, the United States can no longer take its supremacy for granted. Nations from Europe to Eastern Asia are on a fast track to pass the United States in scientific excellence and technological innovation.

The Task Force on the Future of American Innovation has developed a set of benchmarks to assess the international standing of the United States in science and technology. These benchmarks in education, the science and engineering (S&E) workforce, scientific knowledge, innovation, investment and high-tech economic output reveal troubling trends across the research and development (R&D) spectrum. The United States still leads the world in research and discovery, but our advantage is rapidly eroding, and our global competitors may soon overtake us.

Research, education, the technical workforce, scientific discovery, innovation and economic growth are intertwined. To remain competitive on the global stage, we must ensure that each remains vigorous and healthy. That requires sustained investments and informed policies.

Federal support of science and engineering research in universities and national laboratories has been key to America's prosperity for more than half a century. A robust educational system to support and train the best U.S. scientists and engineers and to attract outstanding students from other nations is essential for producing a world-class workforce and enabling the R&D enterprise it underpins. But in recent years federal investments in the physical sciences, math and engineering have not kept pace with the demands of a knowledge economy, declining sharply as a percentage of the gross domestic product. This has placed future innovation and our economic competitiveness at risk.

To help policymakers and others assess U.S. high-tech competitiveness and the health of the American science and engineering enterprise, we have identified key benchmarks in six essential areas—education, the workforce, knowledge creation and new ideas, R&D investments, the high-tech economy, and specific high-tech sectors. We conclude that although the United States still leads the world in research and discovery, our advantage is eroding rapidly as other countries commit significant resources to enhance their own innovative capabilities.

It is essential that we act now; otherwise our global leadership will dwindle, and the talent pool required to support our high-tech economy will evaporate. As a recent report by the Council on Competitiveness recommends, to help address this situation the federal government should:

> *Increase significantly the research budgets of agencies that support basic research in the physical sciences and engineering, and complete the commitment to double the NSF budget. These increases should strive to ensure that the federal commitment of research to all federal agencies totals one percent of U.S. GDP.*[1]

This is not just a question of economic progress. Not only do our economy and quality of life depend critically on a vibrant R&D enterprise, but so too do our national and homeland security. As the Hart-Rudman Commission on National Security stated in 2001:

> *…[T]he U.S. government has seriously underfunded basic scientific research in recent years… [T]he inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century.*[2]

In the post-9/11 era especially, we should heed this warning.

1 *Innovate America*, Council on Competitiveness, December 2004, p. 32 www.compete.org/pdf/NII_Final_Report.pdf

2 *Road Map for National Security: Imperative for Change*. Phase III Report of the U.S. Commission on National Security/21st Century, January 2001, p. ix www.au.af.milau/awc/awcgate/nssg/

Education Benchmarks

Signs of Trouble

- Undergraduate science and engineering (S&E) degrees within the United States are being awarded less frequently than in other countries. For example, the ratio of first university degrees in natural sciences and engineering (NS&E) to the college-age population in the U.S. is only 5.7 degrees per 100. Some European countries, including Spain, Ireland, Sweden, the United Kingdom, France and Finland, award between 8 and 13 degrees per 100. Japan awards 8 per 100, and Taiwan and South Korea each award about 11 per 100.[3]

- As other nations commit significant resources to S&E education, the U.S. share of worldwide undergraduate S&E degrees awarded annually has dropped. In 2000, Asian universities accounted for almost 1.2 million of the world's S&E degrees and European universities (including Russia and Eastern Europe) accounted for about 850,000 S&E degrees, while North American universities accounted for only about 500,000 degrees [4]

- The United States has a smaller share of the worldwide total of S&E doctoral degrees awarded annually than both Asia and Europe. In fact, in 2000, about 89,000 of the approximately 114,000 doctoral degrees earned worldwide in S&E were earned outside the United States.[5]

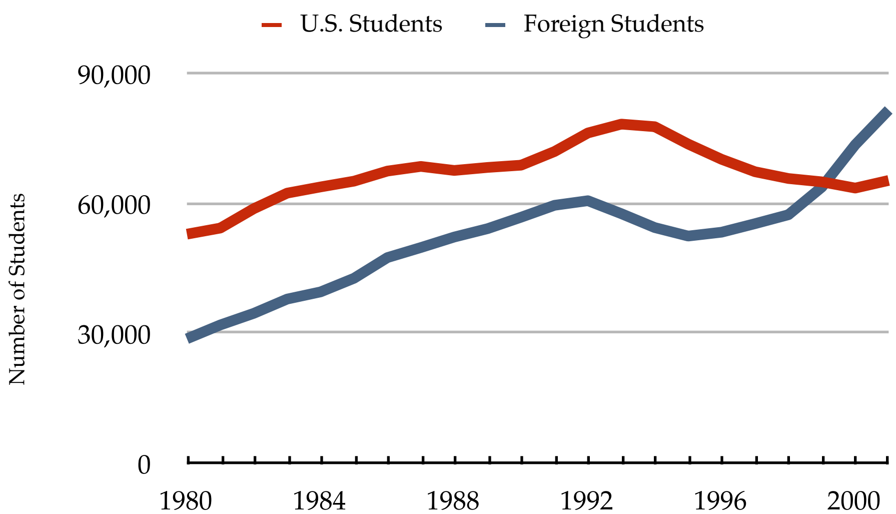
3 NSF Ind. 2004, Fig. 2-34 http://www.nsf.gov/sbe/srs/seind04/c2/fig02-34.htm

4 NSF Ind. 2004, Fig 2-33 http://www.nsf.gov/sbe/srs/seind04/c2/fig02-33.htm

5 NSF Ind. 2004, Appdx. Table 2-36 http://www.nsf.gov/sbe/srs/seind04/append/c2/at02-36.xls

- The proportion of U.S.-citizens in S&E graduate studies within the U.S. is declining. From 1994 to 2001, graduate S&E enrollment in the U.S. declined by 10 percent for U.S. citizens but increased by 25 percent for foreign born students. In 2001 approximately 57 percent of all S&E postdoctoral positions at U.S. universities were held by foreign born scholars.[6]

U.S. GRADUATE INSTITUTIONS: FOREIGN STUDENTS OUTNUMBER U.S. STUDENTS



Source: National Science Foundation, *Graduate Students and Postdoctorates in Science and Engineering: Fall 2001*, Tables 8-9. Compiled by the APS Office of Public Affairs.

6 NSF Ind. Appdx. Table 2-12 http://www.nsf.gov/sbe/srs/seind04/c2/c2h.thml, http://www.nsf.gov/sbe/srs/seind04/append/c2/at02-12.xls

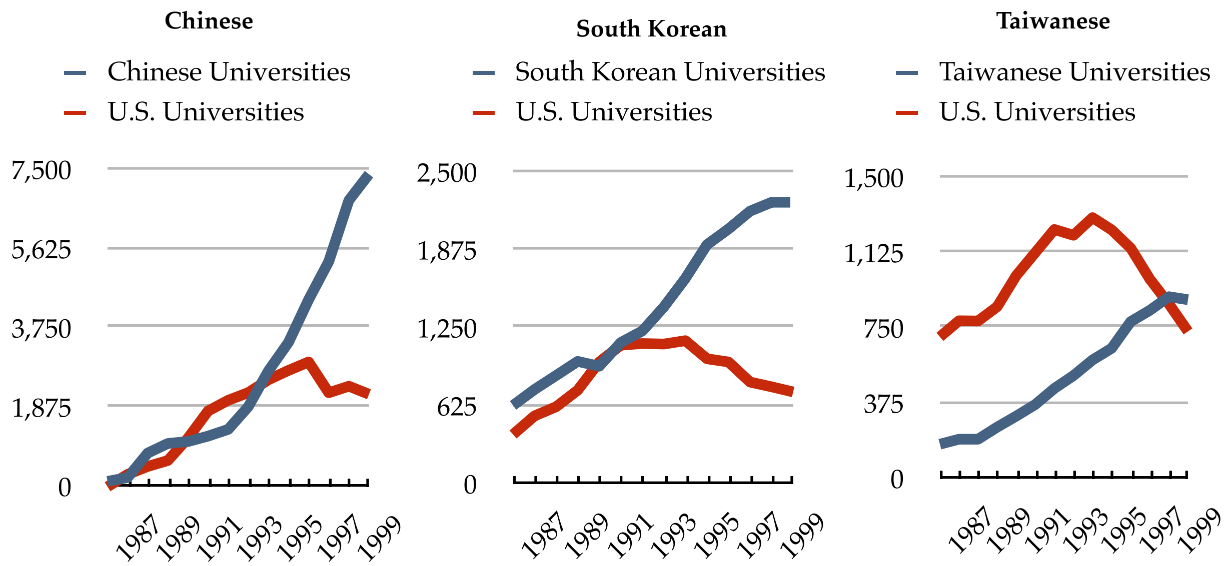
Workforce Benchmarks

Signs of Trouble

- Asian students are less likely to study in the U.S. From 1994 to 1998, the number of Chinese, South Korean, and Taiwanese students who chose to pursue their Ph.D.s at U.S. universities dropped 19 percent (from 4,982 to 4,029). At the same time, the number who chose to pursue their Ph.D.s at universities in their own countries nearly doubled (from 4,983 to 9,942). This indicates that these countries are quickly growing their own higher educational capabilities.

ASIAN PHD. STUDENTS ARE STAYING AT HOME

(1986 - 1999)



Source: National Science Foundation, *Science and Engineering Indicators 2002*, Appendix Table 2-41.
Adapted from Diana Hicks, "Asian countries strengthen their research," *Issues in Science and Technology*, Summer 2004.
Compiled by the APS Office of Public Affairs.

- Since 1980, the number of S&E positions in the U.S. has grown at almost five times the rate of the U.S. civilian workforce as a whole. However, the number of S&E degrees earned by U.S. citizens is growing at a much smaller rate, slightly less than the growth in the total U.S. civilian workforce and much less than the rate of growth in the number of S&E positions available.[7]

- There are rapidly increasing retirements from the S&E field, leading to a potential shortage in the S&E labor market. For example, more than half of those with S&E degrees in the workforce are age 40 or older. Unless more domestic college-age students choose to pursue degrees in critical S&E fields, there is likely to be a major shortage in the high-tech talent required by the U.S. defense industry, key federal

[7] NSF Ind. 2004, Fig 3-1 http://www.nsf.gov/sbe/srs/seind04/c3/fig03-01.htm & NSF Ind. Fig. O-15 http://www.nsf.gov/sbe/srs/seind04/c0/fig00-15.htm

research and national defense agencies (e.g. the Department of Defense, Department of Energy and NASA) and the national laboratories.[8]

- There is increasing global competition in the S&E labor market. Between 1993 and 1997 the Organisation for Economic Development countries increased their number of S&E research jobs by 28 percent, almost twice the 15 percent increase in S&E research jobs in the United States.[9]

8 NSF Ind. 2004, Overview, "Retirements and Demographic Shifts," http://www.nsf.gov/sbe/srs/seind04/c0/c0s1.htm

9 NSF Ind. 2004, Ch. 3, "Researchers in OECD countries, by country/region, 1993, 1995 and 1997," fig. 3-29. http://www.nsf.gov/sbe/srs/seind04/c3/fig03-29.htm

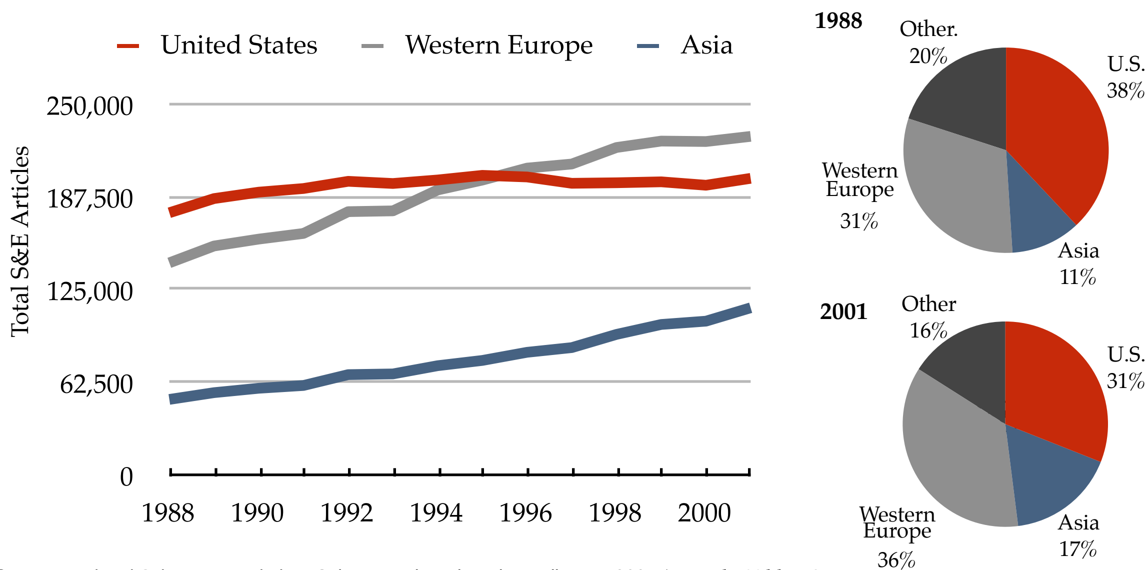
Knowledge Creation and New Ideas Benchmarks

Signs of Trouble

- The U.S. share of S&E papers published worldwide declined from 38 percent in 1988 to 31 percent in 2001. Europe and Asia are responsible for the bulk of growth in scientific papers in recent years. In fact, the U.S. output was passed by Western Europe in the mid-nineties, and Asia's share of the total is rapidly growing.[10]

- From 1988 to 2001 the U.S. increased its number of published S&E articles by only 13 percent. In contrast, Western Europe increased its S&E article output by 59 percent, Japan increased by 67 percent and countries of East Asia, including China, Singapore, Taiwan, and South Korea, increased by 492 percent. Though both Japan and East Asia started from a far smaller base in 1988, and still do not publish as many articles as the U.S., their growth rate is dramatic.[11]

S&E ARTICLES: U.S. ALREADY PASSED BY WESTERN EUROPE, ASIA RAPIDLY CLOSING



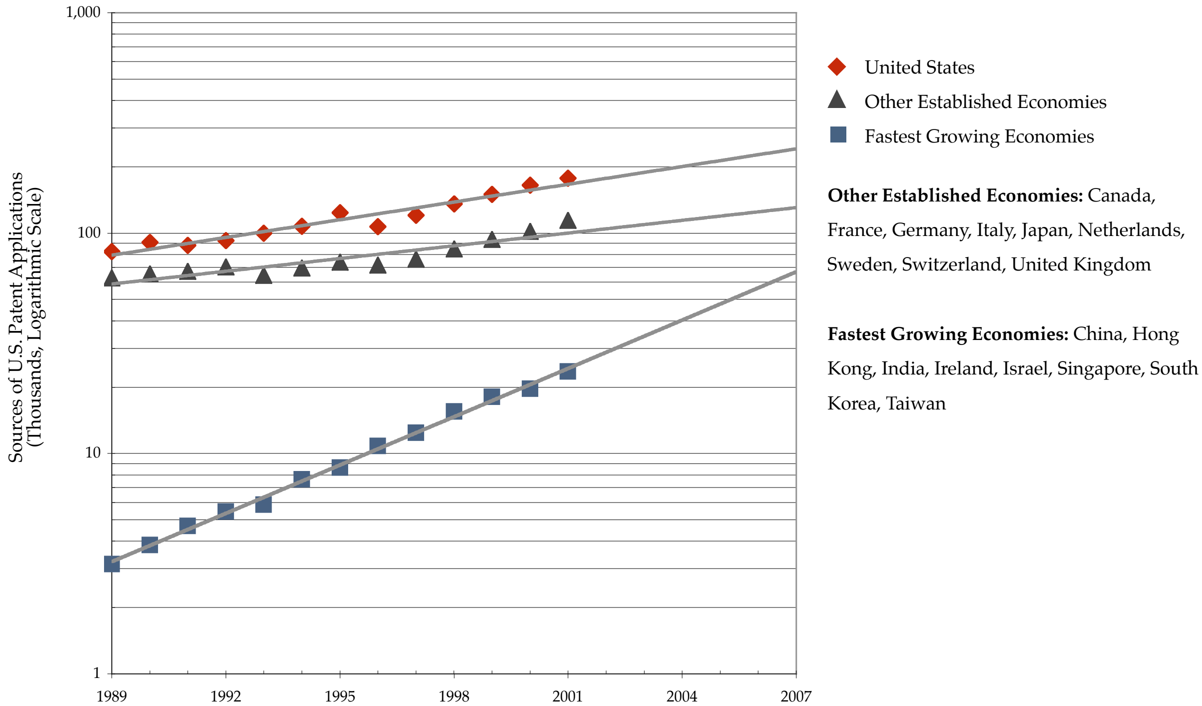
Source: National Science Foundation, *Science and Engineering Indicators 2004*.Appendix Table 5-35. Compiled by the APS Office of Public Affairs.

10 NSF Ind. 2004, Fig. 5-30 http://pubs.acs.org/cen/science/8224/pdf/8224sci2.pdf

11 NSF Ind. 2004, Appdx. Table 5-35 http://www.nsf.gov/sbe/srs/seind04/append/c5/at05-35.xls

- U.S. Patent applications from the Asian countries of China, India, Singapore, South Korea, and Taiwan grew by 759 percent from 1989 to 2001. Patent applications from the U.S. during the same period grew more slowly at 116 percent (though, as with the above, it should be mentioned that the Asian countries started out at a much lower base level).[12]

U.S. PATENT APPLICATIONS: FASTEST GROWING ECONOMIES GAINING ON U.S. RAPIDLY



Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-11.
Compiled by the APS Office of Public Affairs

- The U.S. share of worldwide citations is shrinking. Whereas in 1992 the U.S. share of citations was 52 percent, by 2001 it had declined to 44 percent of the worldwide total.[13]

12 NSF Ind. 2004, Appdx. Table 6-11 http://www.nsf.gov/sbe/srs/seind04/append/c6/at06-11.xls

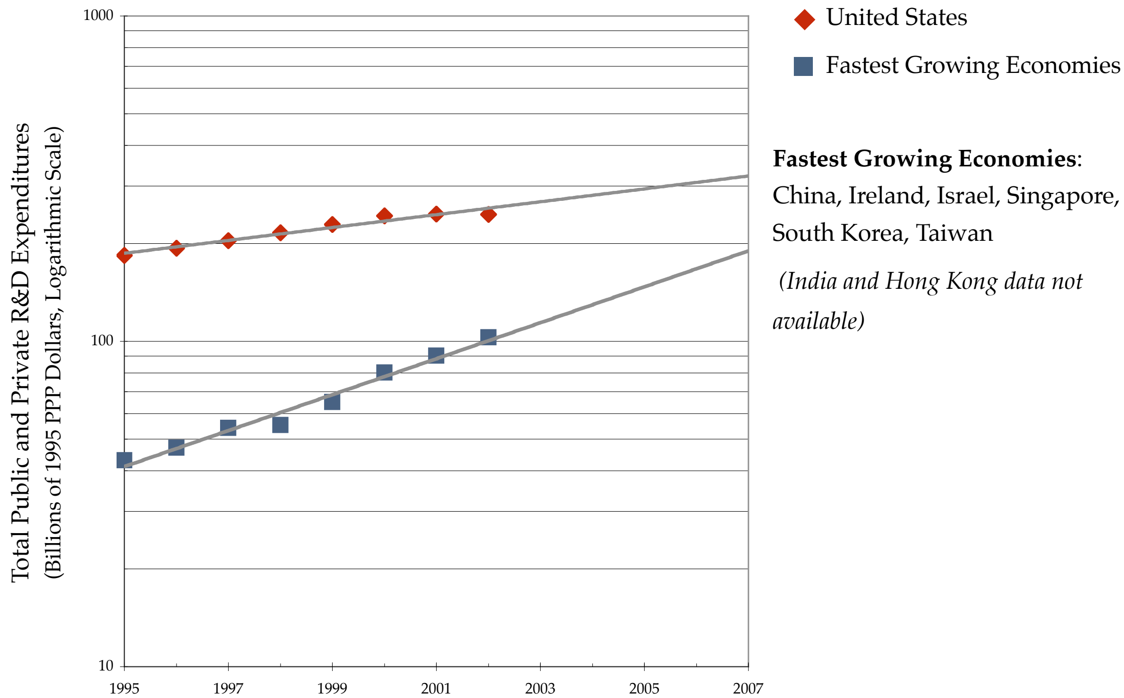
13 NSF Ind. 2004, Appdx. Table 5-48 http://www.nsf.gov/sbe/srs/seind04/append/c5/at05-48.xls

R&D Investment Benchmarks

Signs of Trouble

- Collectively, the world's fastest growing economies are on track to catch up to U.S. R&D investment. From 1995 through 2001, the emerging economies of China, South Korea, and Taiwan increased their gross R&D investments by about 140 percent. During the same period the U.S. increased its investments by 34 percent.

TOTAL R&D INVESTMENTS: FASTEST GROWING ECONOMIES GAINING RAPIDLY ON U.S.



Fastest Growing Economies: China, Ireland, Israel, Singapore, South Korea, Taiwan

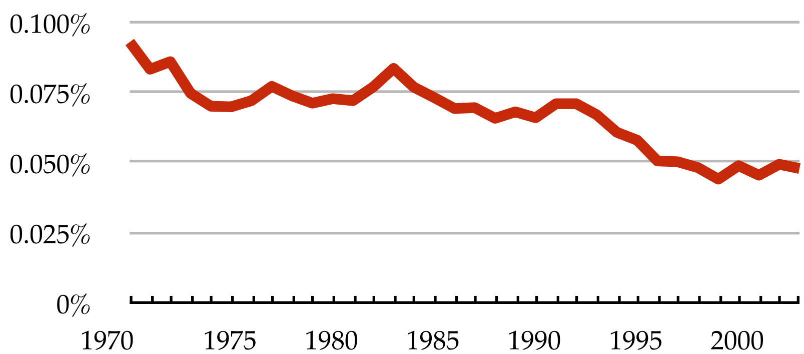
(India and Hong Kong data not available)

Source: Organisation for Economic Cooperation and Development, *Main Science and Technology Indicators*, May 2003.
Compiled by the APS Office of Public Affairs

- Within the U.S., federal funding of basic research in engineering and physical sciences has experienced little to no growth over the last thirty years. In fact, as a percentage of GDP, funding for physical science research has been in a thirty year decline.

FEDERAL INVESTMENT IN PHYSICAL SCIENCES IN SIGNIFICANT DECLINE

Ratio of U.S. Federal Government Funding for Physical Sciences Research to U.S. Gross Domestic Product: 1970-2003



Source: American Association for the Advancement of Science. www.aaas.org/spp/rd/guidisc.htm
Compiled by the APS Office of Public Affairs

- Since the 1980s there has been a dynamic shift in the source of funding for R&D. U.S. private sector investment in R&D now far exceeds federal investment in R&D, providing over 68 percent of all domestic R&D. However, private funding tends to cycle with business patterns and focus on short-term results. Of these private funds, 71 percent of these private funds were for development, not basic research.[14]

- Between 1995 and 2002, China doubled the percentage of its GDP invested in R&D, from 0.6 to 1.2 percent. Also, China intends to increase the proportion of science spending devoted to basic research by more than 200 percent, to about 20 percent of its science budget, in the next 10 years.[15]

- From 1995 to 2002, Japanese businesses increased their R&D spending from 2.12 percent to 2.32 percent of GDP, and European businesses increased their R&D spending from 1.15 percent to 1.17 percent of GDP. U.S. businesses, however, actually decreased their level of spending, from more than 2 percent to 1.87 percent of GDP.[16]

14 NSF Ind. 2004, Fig. O-3 http://www.nsf.gov/sbe/srs/seind04/c0/fig00-03.htm and Lieberman White Paper, May 2004, p. 15 and http://lieberman.senate.gov/newsroom/whitepapers/Offshoring.pdf and PCAST Report, Oct. 2002 http://www.ostp.gov/PCAST/FINAL%20R&D%20REPORT%20WITH%20LETTERS.pdf

15 "OECD Countries Spend More on Research and Development, Face New Challenges." OECD, 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html, and Jia, Hepeng. "Funding Boost for Basic Science in China." *SciDevNet*, 2005, http://www.scidev.net/News/index.cfm?fuseaction=readnews&itemid=1941&language=1

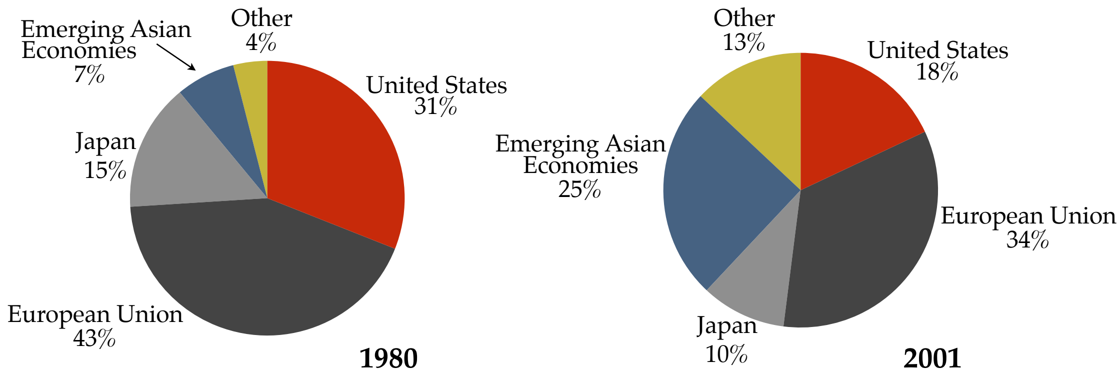
16 "OECD Countries Spend More on Research and Development, Face New Challenges." OECD, 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html

High-tech Economy Benchmarks

Signs of Trouble

- The U.S. share of worldwide high-tech exports has been in a 20-year decline. From 1980 until 2001 the U.S. share fell from 31 percent to 18 percent. At the same time, the global share for China, South Korea, and other emerging Asian countries increased from just 7 percent to 25 percent.

HIGH-TECH INDUSTRY EXPORTS: U.S. LOSING WORLD SHARE



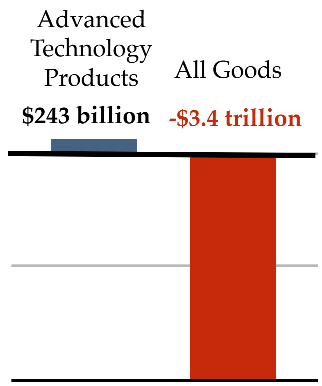
Emerging Asian Economies: China, South Korea, Taiwan, Singapore, Hong Kong, India

Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-1
Compiled by the Association of American Universities

- During the 1990s, the U.S. maintained a trade surplus for high-tech products even as the trade balance for other goods plummeted. But since 2001, even the trade balance for high-tech has fallen into deficit.

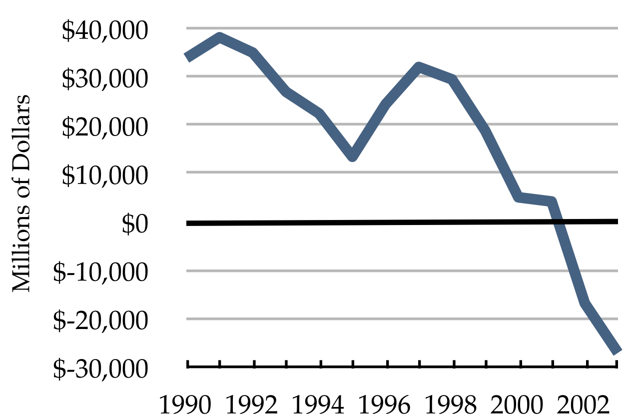
HIGH-TECH HAS DELIVERED FOR THE U.S. ECONOMY …

Cumulative U.S. Trade Balance, 1990-2003



…BUT WILL IT CONTINUE?

U.S. Trade Balance for High-Tech Products, 1990-2003

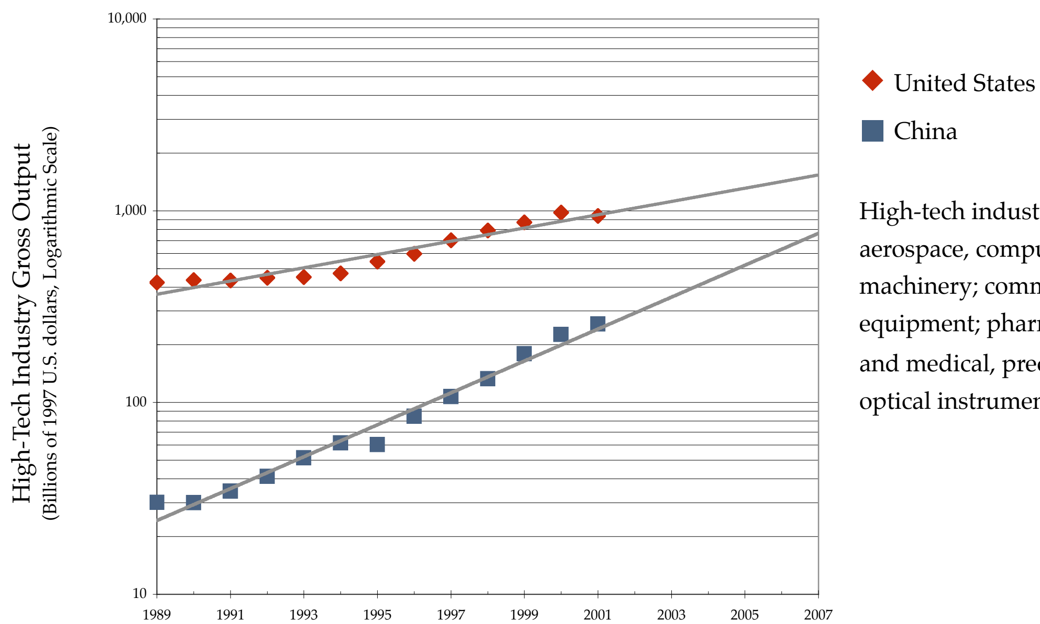


Source: U.S. Census Bureau Foreign Trade Statistics, *U.S. International Trade in Goods and Services.*
Compiled by the APS Office of Public Affairs.

- China now rivals the U.S. as a destination for foreign capital and in 2003 was the largest recipient of foreign direct investment (FDI) in the world with $53.5 billion flowing into the country.[17] Investment in U.S. businesses, meanwhile, dropped from $314 billion in 2000 to $30 billion in 2003 and $91 billion through the first three quarters of 2004.[18]

- Even while the U.S. high-tech industry grew rapidly throughout the 1990s, the high-tech industry in many Asian countries grew even faster. For example, from 1989 to 2001, U.S. high-tech output doubled, growing from $423 billion to $940 billion, but China's high-tech output shot up more than 8-fold, from $30 billion to $257 billion.

HIGH-TECH INDUSTRY OUTPUT: CHINA RAPIDLY GAINING ON U.S.



High-tech industry includes aerospace, computers and office machinery; communications equipment; pharmaceuticals ; and medical, precision and optical instruments.

Source: National Science Foundation, *Science and Engineering Indicators 2004*, Appendix Table 6-1.
Compiled by the APS Office of Public Affairs

17 Lieberman White Paper, May 2004, p.18 http://lieberman.senate.gov/newsroom/whitepapers/Offshoring.pdf

18 U.S. Department of Commerce, Bureau of Economic Analysis http://www.bea.doc.gov/bea/di/fdi21web.htm

Sector Benchmarks

Signs of Trouble

NANOTECHNOLOGY

- Asian countries are investing significantly in nanotechnology, and may have already surpassed the U.S. in this promising area of research. For example, *Small Times* reported last year: "Japan's nanotechnology budget for fiscal 2004 rose 3.1 percent to $875 million, according to Japan's Council for Science and Technology Policy. Meanwhile, the two main government ministries responsible for about 90 percent of the country's nanotechnology research programs are both seeing their budgets increased."[19]

- China has also been investing heavily in nanotechnology and already leads the U.S. in some key areas. For example: "Chinese scientists at Beijing's Tsinghua University announced that they have significantly increased the rate at which carbon nanotubes can be produced. The scientists say they have developed a new approach that produces carbon nanotubes 15 kilograms per hour, 60 times faster than the speed at which U.S. scientists had been producing them."[20] In recent surveys, China ranked third, after the U.S. and Japan, in worldwide nanotechnology patents and publications.[21]

INFORMATION TECHNOLOGY

- As the President's Council of Advisors for Science and Technology (PCAST) said in January, 2004: "In the face of global competition, U.S. information technology manufacturing has declined significantly since the 1970's, with an acceleration of the decline over the past five years."[22]

- As PCAST also noted, "Because of its overwhelming population compared to other Asian competitors, China's rise as a high tech manufacturer has caused increasing concerns. China is a large emerging market and its industrial and economic policies associated with expanding this sector are likely to continue indefinitely."[23]

- The U. S. ranks 13th out of 15 highly developed countries in household broadband penetration.[24]

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19 "Japan Boosts Nanotechnology Budget and Industrial Cooperation," *Small Times,* 15 Apr. 2004 http://www.smalltimes.com/document_display.cfm?document_id=7735

20 "China, Emboldened by Breakthroughs, Sets Out to Become Nanotech Power," *Small Times*, 17 Dec. 2001 http://www.smalltimes.com/print_doc.cfm?doc_id=2736

21 "Status of Nanotech Industry in China." *Asia Pacific Nanotech Weekly*. Vol. 2, article #24. June 23, 2004. http://www.nanoworld.jp/apnw/articles/2-24.php

22 PCAST report, Jan. 2004, pg. 6, http://www.ostp.gov/PCAST/FINALPCASTITManuf%20ReportPackage.pdf.

23 PCAST report, Jan. 2004, pg. 8 http://www.ostp.gov/PCAST/FINALPCASTITManuf%20ReportPackage.pdf

24 ITU Strategy and Policy Unit Newlog, 15 Sept. 2004 http://www.itu.int/osg/spu/newslog/categories/indicatorsAndStatistics/2004/09/15.html

ENERGY

- In the mid-1990s, the U.S. significantly scaled back its Fusion Energy Science Program, essentially ceding scientific dominance in fusion research to Europe and Japan. After these cutbacks, Europe's fusion program grew to 2.5 times the size of the US fusion program and Japan's program grew to about 1.5 times the size of the US program.[25]

- "Current expansion and growth prospects for nuclear power are centered in Asia. Twenty of the last 29 reactors to be connected to national grids are in the Far East and South Asia. And, of the 31 units under construction worldwide, 18 are located in India, Japan, South Korea, China, and Taiwan."[26] Meanwhile, most US utilities long ago dropped plans to build more nuclear reactors. In fact, no new nuclear power plants have been ordered since 1978.[27]

AEROSPACE

- From 1998 through 2003, the balance of trade in aircraft — for years one of the strongest U.S. export sectors — fell from $39 billion to $24 billion, a loss of $15 billion, reflecting increased sales of foreign-made commercial aircraft to U.S. carriers.[28]

BIOTECHNOLOGY

- China is making rapid progress in biotechnology. "The production value of the biotechnology industry throughout the country was 200 million yuan ($24 million U.S.) in 1986. In 2000, the figure reached 20 billion yuan ($2.4 billion U.S.). The output value of China's pharmaceutical industry was 200 billion yuan last year, with an annual growth rate of 20 percent in each of the previous five years."[29]

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25 Office of Fusion Energy Sciences, Aug. 1996, pp. 1 & 7 http://www.ofes.fusion.doe.gov/FusionDocuments/StrategicPlan.pdf

26 Security, Innovation, and Human Capital in the Global Interest, Speech by Dr. Shirley Ann Jackson, Ph.D., President, Rensselaer Polytechnic Institute, Center for Strategic and International Studies, June 17, 2004.

27 "Work halted on last NPPs under construction in the US", WISE News Communique, December 19, 1994. :http://www.antenna.nł wise/index.html?http://www.antenna.nł wise/424/4196.html

28 World Trade Atlas, based on U.S. Department of Commerce data

29 "Biotechnology could have bright future in Chinese market, experts" in *China View*, 7 July 2004. http://news.xinhuanet.com/english/2004-07/20/content_1620375.htm

References

Barrett, Craig. "The Next Economy". *Foreign Policy Magazine*. September/October 2004 Ed.

"Biotechnology Could Have Bright Future in Chinese Markets". China View. 7 Sep 2004. Xinhua Online. http://news.xinhuanet.com/english/2004-07/20/content_1620375.htm

Council on Competitiveness, *Innovate America*, December 2004. http://www.compete.org/pdf/NII_Final_Report.pdf

Hicks, Diana. "Asian countries strengthen their research," *Issues in Science and Technology*, Summer 2004.

International Telecommunications Union, "Ranking Economies by Broadband Penetration," *ITU Strategy and Policy Unit Newlog*, 15 Sept. 2004 http://www.itu.int/osg/spu/newslog/2004/09/15.html

Jackson, Shirley Ann. "Security, Innovation, and Human Capital in the Global Interest." Speech. Center for Strategic and International Studies, June 17, 2004.

Kallender, Paul. "Japan Boosts Nanotechnology Budget and Industrial Cooperation". *Small Times*. 15 Apr 2004. http://www.smalltimes.com/document_display.cfm?document_id=7735

Lieberman, Sen. Joseph. "Offshore Outsourcing and America's Competitive Edge: Losing in the High Technology R&D and Services Sector". 11 May 2004.

Lin-Liu, Jen. "China, Emboldened by Breakthroughs, Sets Out to Become Nanotech Power". *Small Times* http://www.smalltimes.com/print_doc.cfm?doc_id=2736.

National Science Board. *Science and Engineering Indicators-2004*. Arlington, VA: National Science Foundation, 2004. NSB-04-07.

"OECD Countries Spend More on Research and Development, Face New Challenges." Organisation for Economic Co-operation and Development. 23 Dec 2004. http://www.oecd.org/document/2/0,2340,en_2649_201185_34100162_1_1_1_1,00.html

U.S. Commission on National Security/21st Century. "Road Map for National Security: Imperative for Change." 15 Feb 2001.

President's Council of Advisors on Science and Technology. "Sustaining the Nations Innovation Ecosystems, Information Technology Manufacturing and Competitiveness." 16 Jan 2004.

President's Council of Advisors on Science and Technology. "Assessing the U.S. R&D Investment," 16 October 2002.

Office of Fusion Energy Sciences, Office of Energy Research and U.S. Department of Energy. "Strategic Plan for the Restructured U.S. Fusion Energy Science Program." August 1996. http://www.ofes.fusion.doe.gov/FusionDocuments/StrategicPlan.pdf

"Work Halted on Last NPPs Under Construction in US". Wise News Communiqué. 19 Dec 2004. http://www.antenna.nl/wise/index.html?http://www.antenna.nl/wise/424/4196.html

Innovation is America's Economic Heartbeat.

Don't Flat Line our Future!

THE TASK FORCE ON THE FUTURE OF AMERICAN INNOVATION

IS

Association of American Universities (AAU) 1900

ACS

AeA Advancing the Business of Technology

Agilent Technologies

AMS American Mathematical Society

APS

ASTRA Alliance for Science & Technology Research in America

CompTIA

Council on Competitiveness

Computing Research Association CRA

Computer Systems Policy Project CSPP

hp invent

IBM

intel

Microsoft

MRS

NASULGC National Association of State Universities and Land-Grant Colleges

NAM National Association of Manufacturers

The Science Coalition

SIA Semiconductor Industry Association

SURA

Texas Instruments

http://www.bcs.org/BCS/Awards/Events/GrandChallenges/conferencereports

Grand Challenges in Computing

GC04

Research

Edited by
Tony Hoare and Robin Milner

Organised by:

BCS THE BRITISH COMPUTER SOCIETY

CPHC Council of Professors and Heads of Computing

EPSRC Engineering and Physical Sciences Research Council

The IEE

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--- Article to appear in March 2005 *Computing Research News* ---

CS Bachelor's Degree Production Grows in 2004; Poised for Decline
by Jay Vegso, CRA Staff

CRA's Taulbee Survey of Ph.D.-granting Computer Science (CS) and Computer Engineering departments in North America has been conducted each Fall since 1974. Results from the most recent survey were provided to participants and CRA members in February. They will be published on CRA's website (www.cra.org/statistics/) and in Computing Research News in May. Due to the interest in the data on undergraduate degrees, however, CRA has chosen to release a portion of the results early.

This article reports on CS bachelor's degree enrollments and production among Ph.D.-granting departments in the United States since the mid-1990s. For figures that group CS departments by rank, the rankings are based on information collected in the 1995 assessment of research and doctorate programs in the U.S. conducted by the National Research Council (see http://www.cra.org/nrc).

As can be seen in Figure 1, total bachelor's degree production increased in the 2003/2004 academic year to 14,185. Nevertheless, this was its slowest rate of growth (5 percent) since the mid-1990s. In addition, growth in the number of degrees granted by the top 36 departments ranked by the NRC began to slow in 2001/2002, and production shrank last year by 3 percent. The median number of degrees granted by the top 36 departments has declined for the past two years, to 109. At the same time, growth among those ranked 37 and above continued at about 10 percent last year, and the median number of degrees granted by them increased to 65.

It is important to remember that these results are for Ph.D.-granting departments only. The National Science Foundation publishes results for all institutions that grant CS degrees but its most recent data are from 2000/2001. Traditionally, the Taulbee Survey's Ph.D.-granting schools have produced a little below 30 percent of the undergraduate CS degrees reported by the NSF. As a result, it is possible to estimate that a little more than 50,000 undergraduate CS degrees were granted in 2003/2004.

While the current undergraduate CS degree production numbers are strong, they appear set to decline in coming years. The number of students that declared their major in CS has declined for the past four years and is now 39 percent lower than in the Fall of 2000 (Figure 2). The number of new CS majors among departments ranked 37 and above has declined steadily since 2000, and since 2002 for those ranked in the top 36. The impact of these declines is now being felt among enrollments, which have decreased by 7 percent in each of the past two years (Figure 3). The greatest decline in the past few years has occurred among the top 36 departments, which saw enrollments fall by 19 percent between 1999/2000 and 2003/2004. In comparison, enrollments for those ranked 37 and above dropped 13 percent between their peak in 2001/2002 and last year.

A downturn in undergraduate CS degree production therefore seems likely in the coming decade. This is not surprising in light of the volatile history of the field. According to the NSF, undergraduate CS production nearly quadrupled between 1980 and 1986, to over 42,000 degrees. This period was followed by a swift decline and leveling off during the 1990s, with several years during which the number of degrees granted hovered at around 25,000. During the late 1990s, CS degree production again surged, to over 43,000 in 2001. Another downward trend was foreseeable. Indeed, survey results from the Higher Education Research Institute have indicated a declining interest in CS as a major among incoming Freshman for the last five years: from 3.8 percent in 1999, to 1.4 percent in 2004. How much of an impact this will have on degree production, and whether this will simply be part of a pattern, are unknown.

Figure 1. CS Bachelor's Degrees Granted

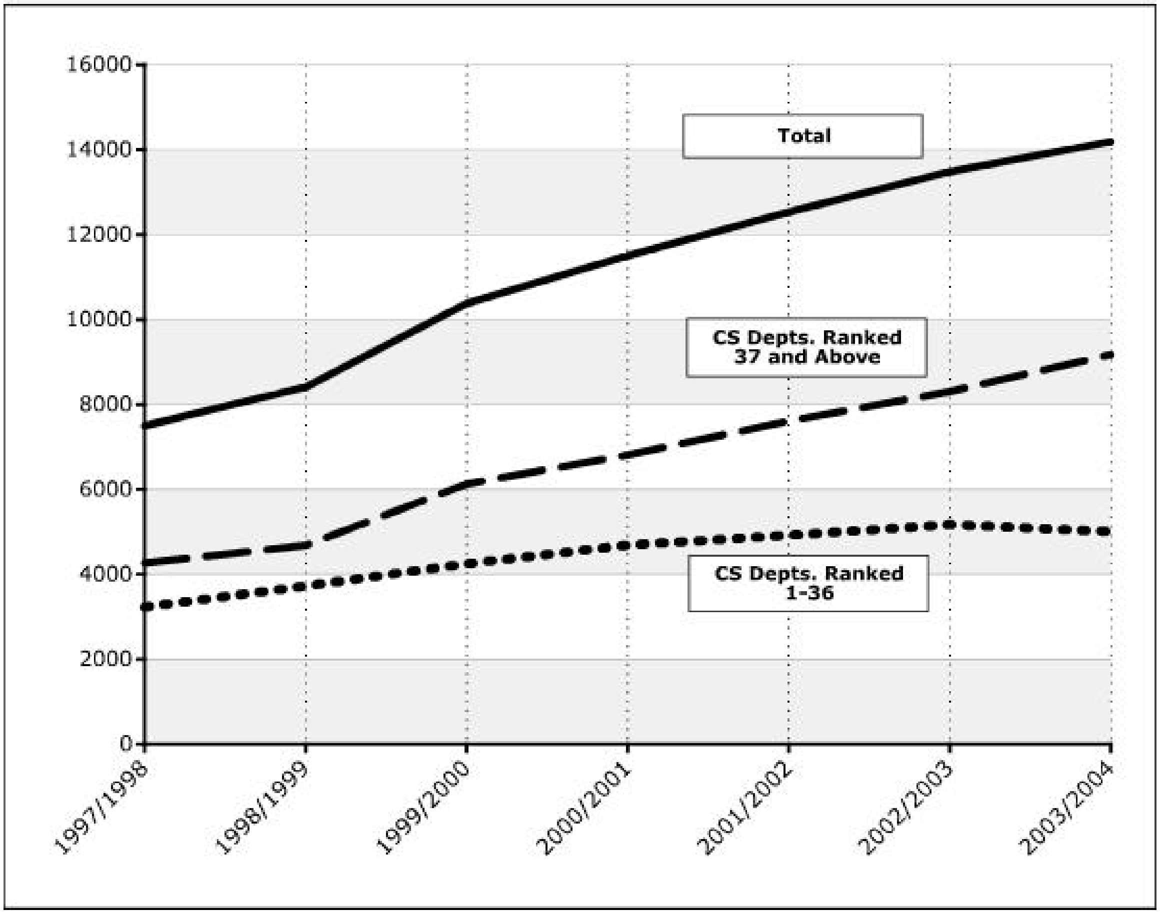


Figure 2. Newly Declared CS Majors

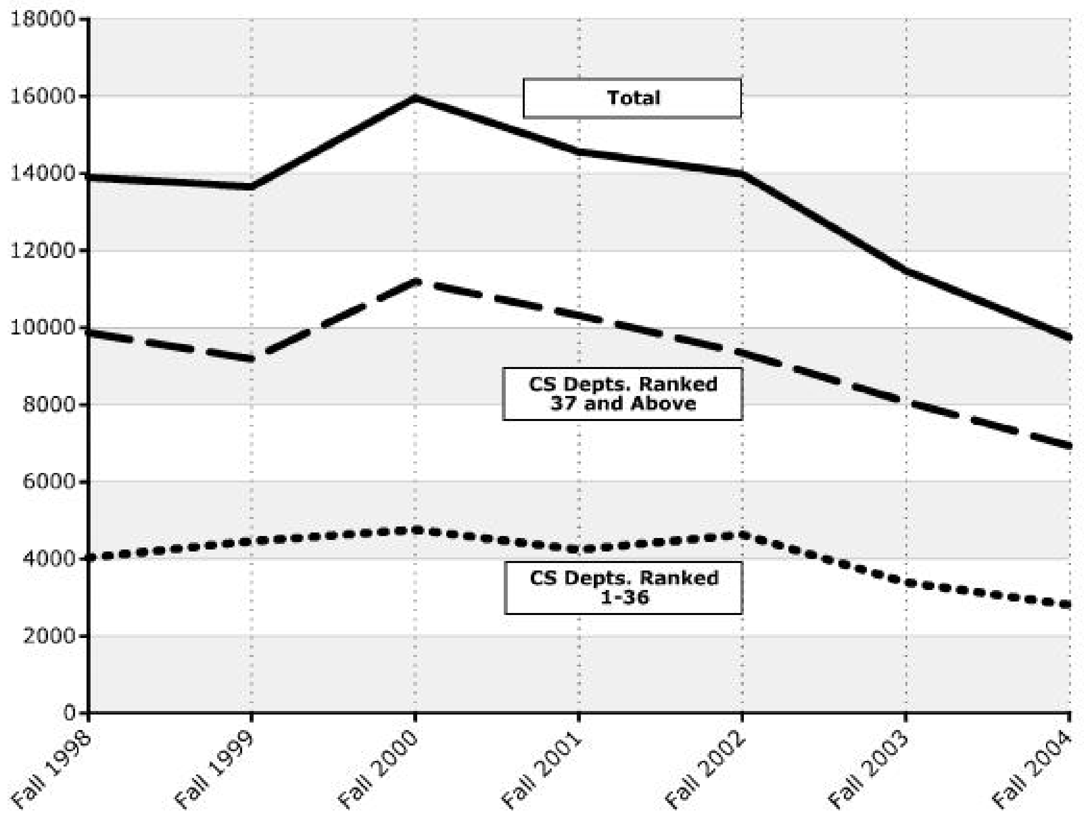
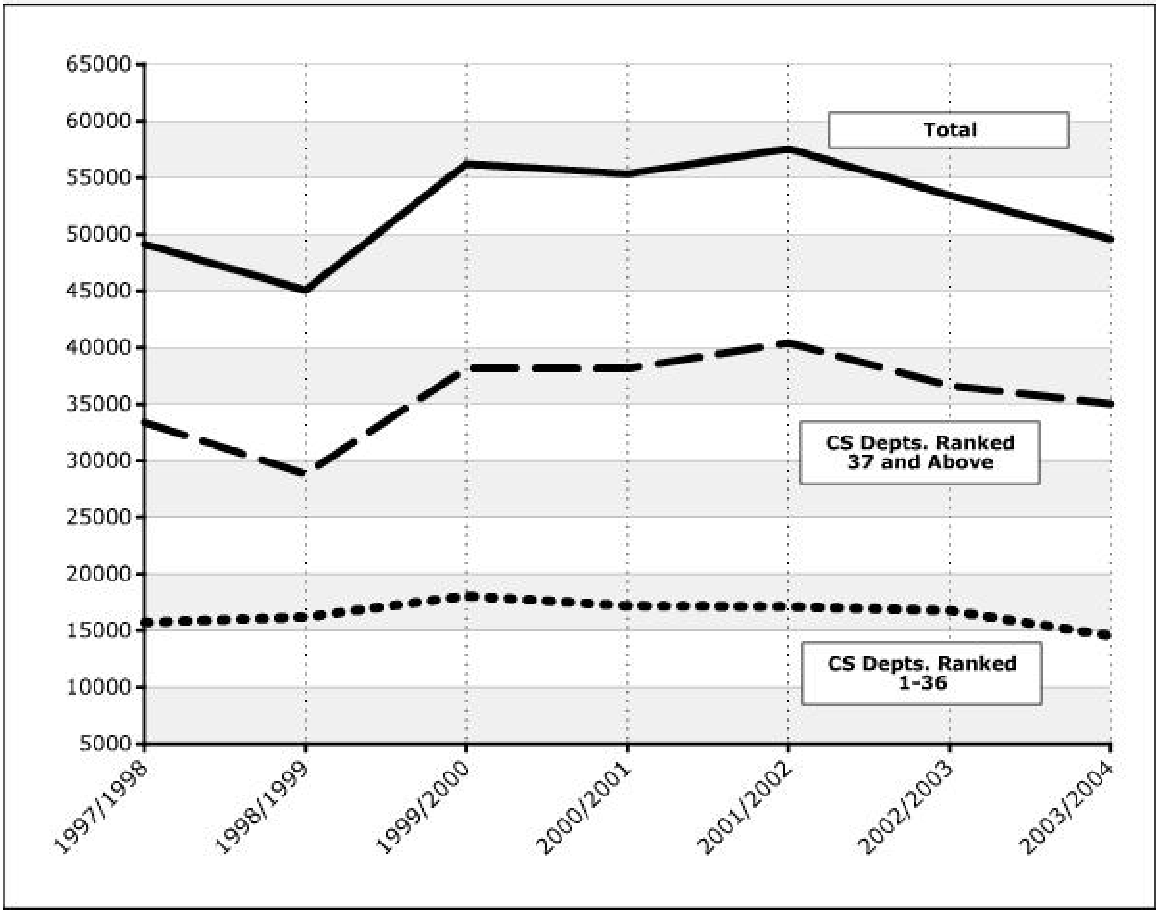


Figure 3. Undergraduate CS Degree Enrollments



Data on Enrollments, Faculty Size and Degrees Granted

Computing Research Association

February 2005

NOT FOR DISTRIBUTION

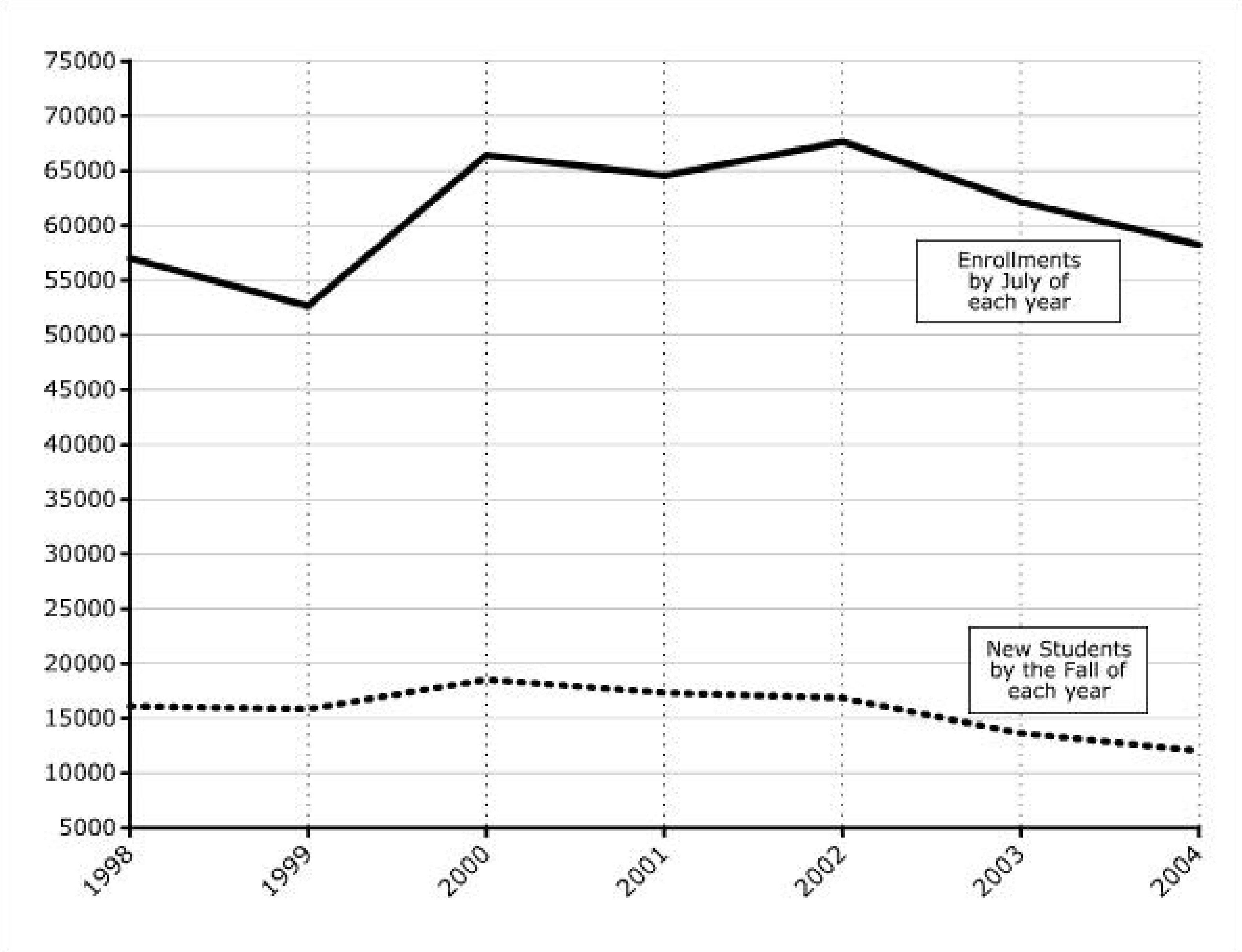
HERI's American Freshman Survey

Percent of incoming students interested in majoring in Computer Science

1995	2.1
1996	2.6
1997	3.1
1998	3.5
1999	3.8
2000	3.7
2001	3.3
2002	2.2
2003	1.7
2004	1.4

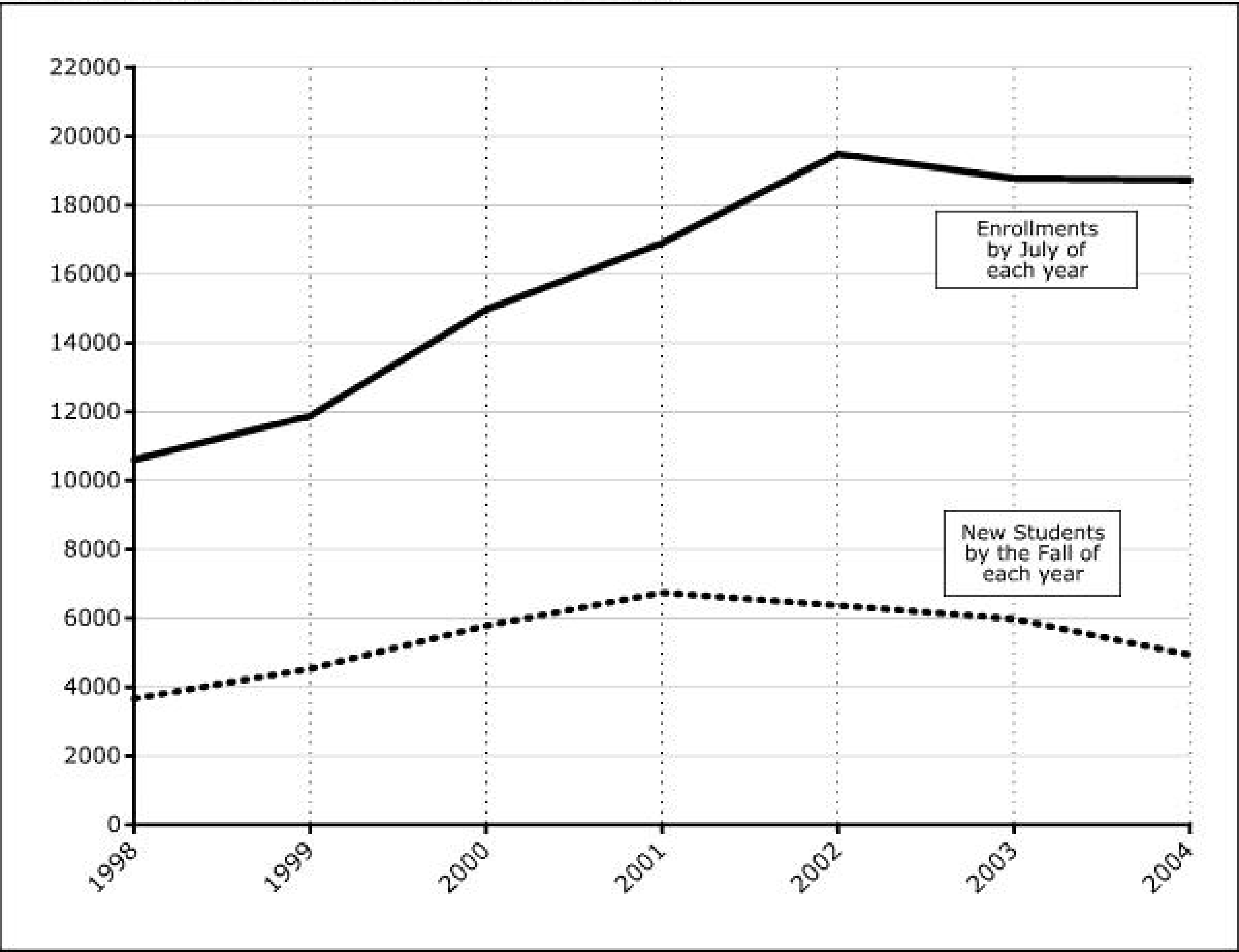
CS Bachelor's Degree Enrollments and New Students

US PhD-granting departments only. CRA Taulbee Survey.



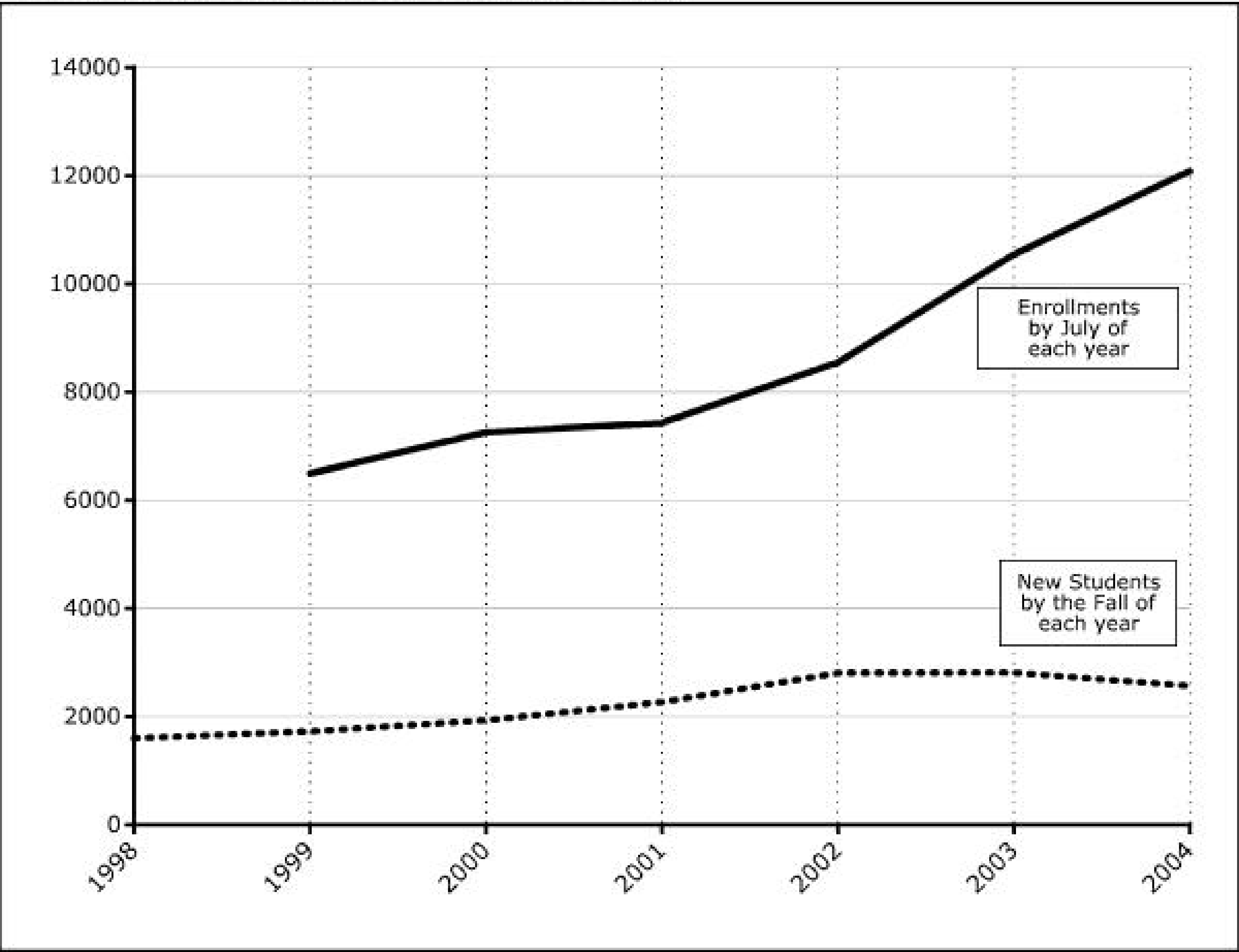
CS Master's Degree Enrollments and New Students

US PhD-granting departments only. CRA Taulbee Survey.



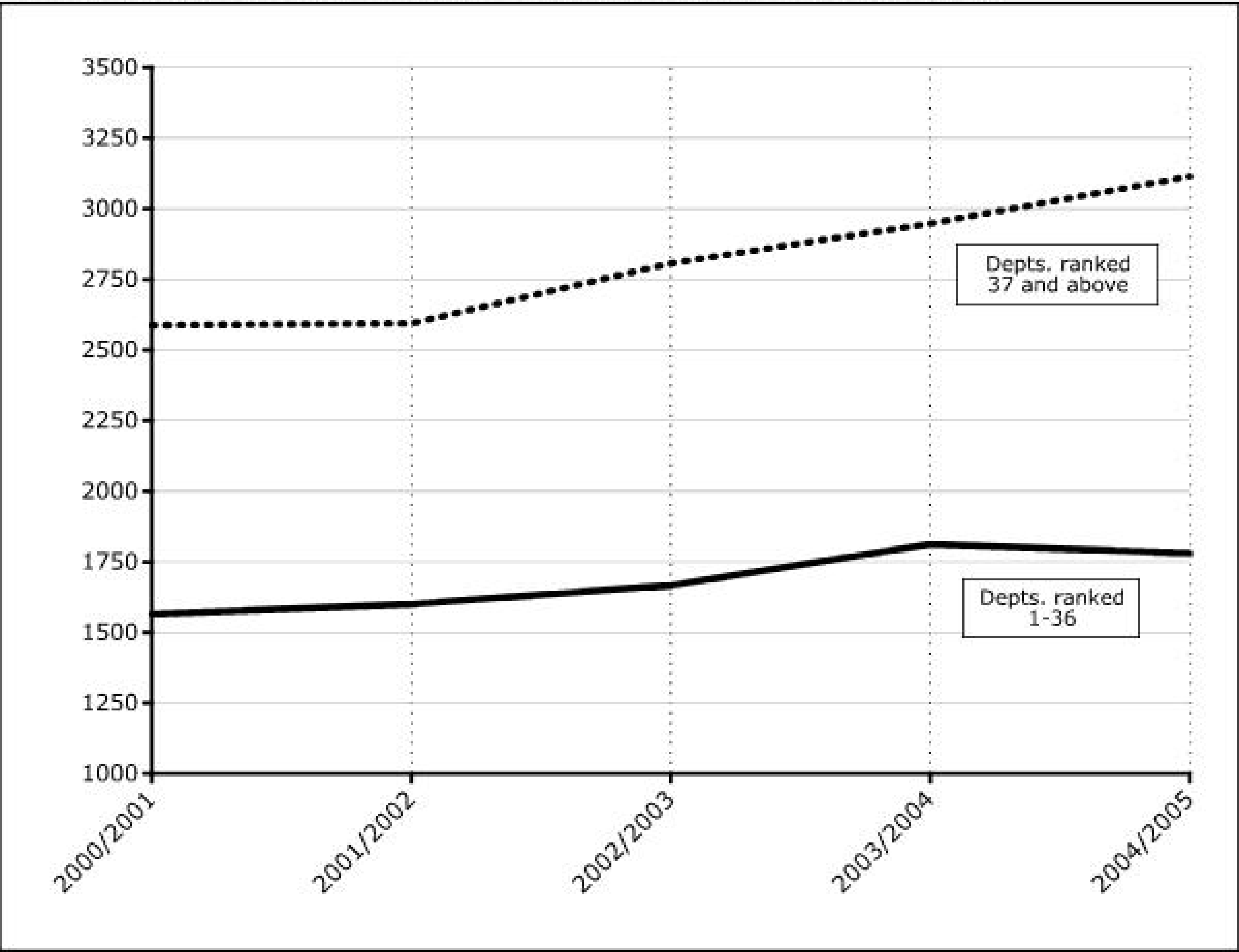
CS Doctoral Degree Enrollments and New Students

US PhD-granting departments only. CRA Taulbee Survey.



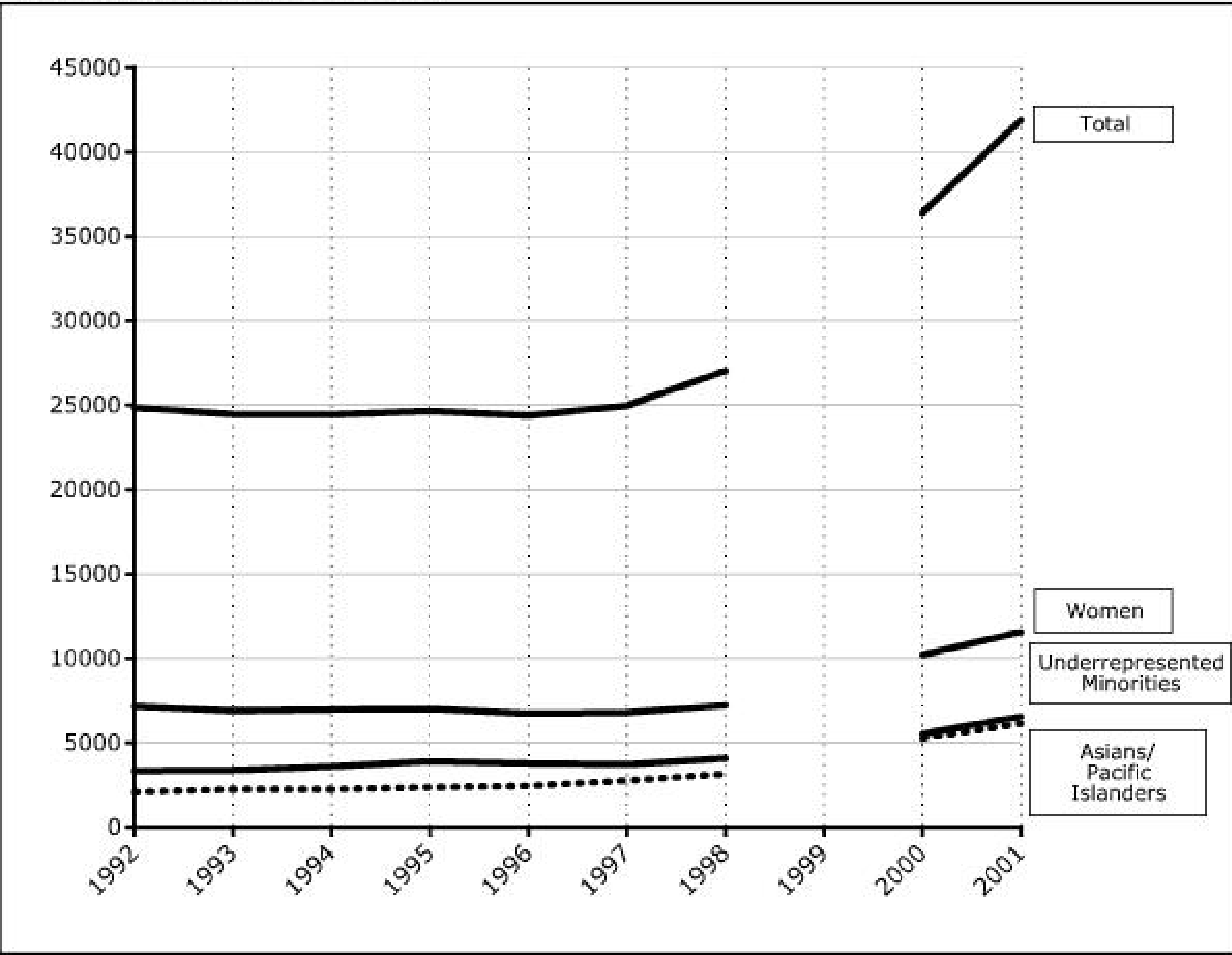
CS Dept. Faculty Size

US PhD-granting depts only. CRA Taulbee Survey. Rankings by 1993/95 NRC study.



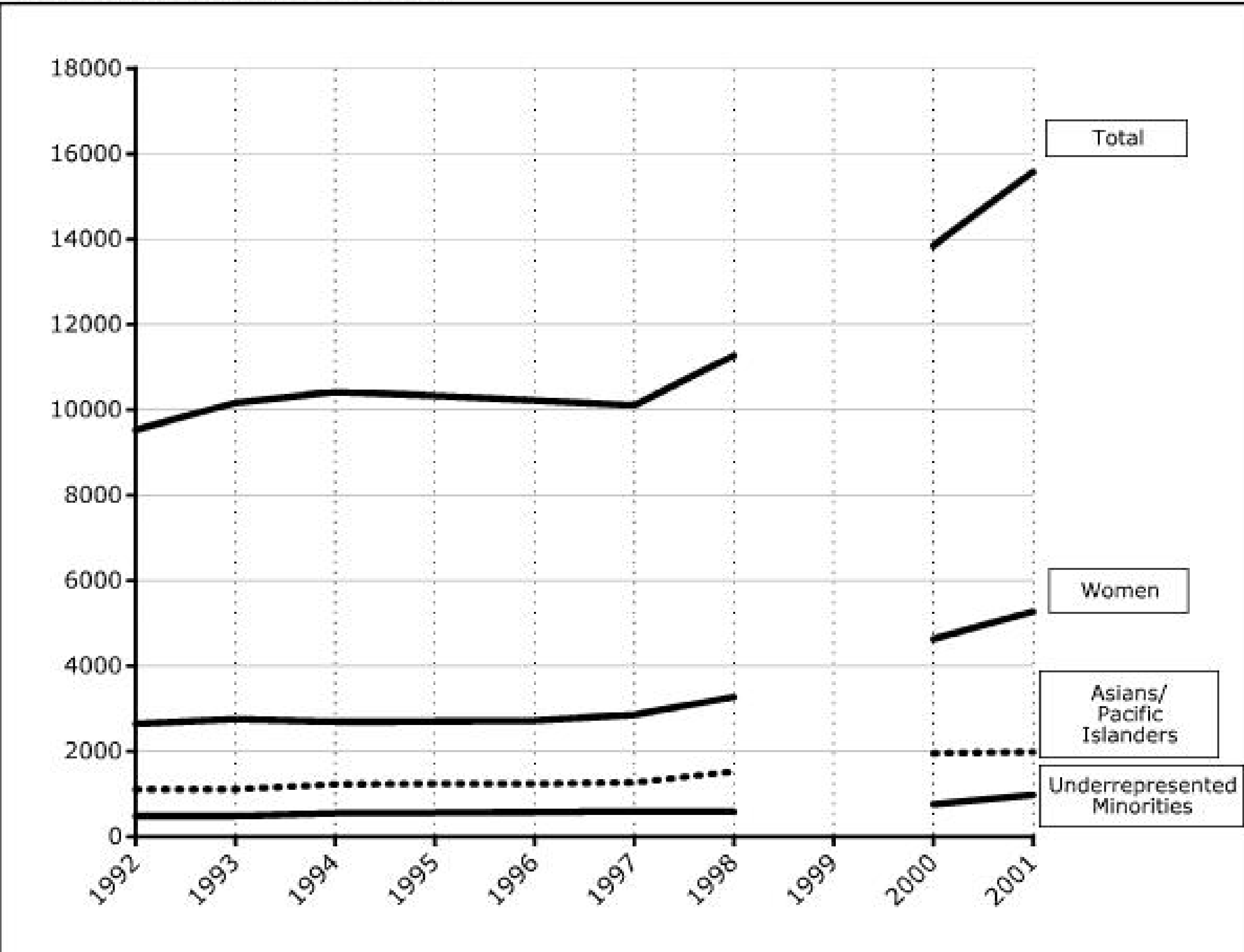
CS Bachelor's Degrees

NSF Data. No data reported for 1999.



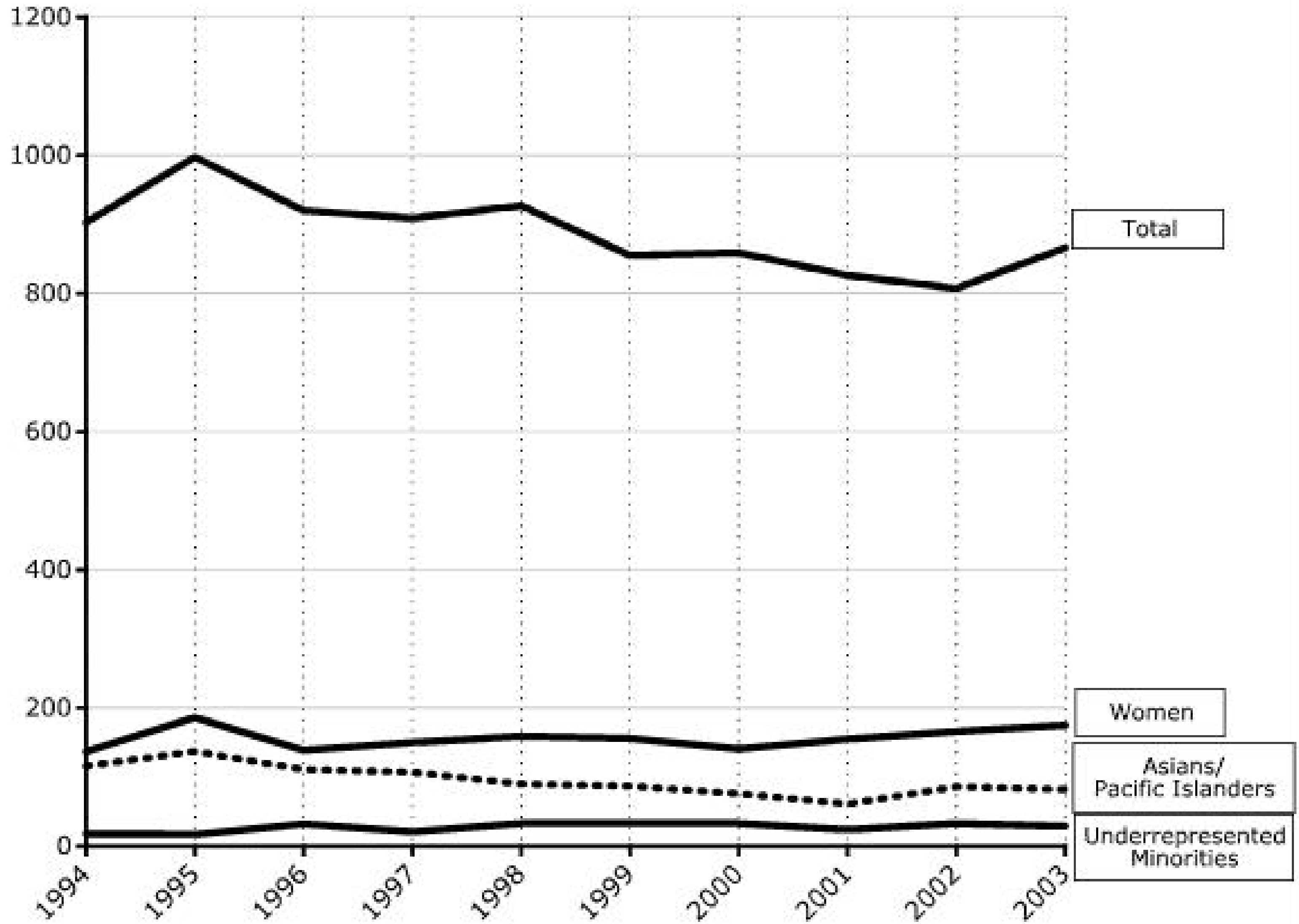
CS Master's Degrees

NSF Data. No data reported for 1999.



CS Doctorate Degrees

NSF Data



BusinessWeek online

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FEBRUARY 7, 2005

NEWS: ANALYSIS & COMMENTARY

Commentary: Getting Girls To The Lab Bench

To remain competitive, the U.S. must close the gender gap in science

Lucie Yueqi Guo and Xianlin Li are proof that girls can love science, too. The two seniors at North Carolina School of Science & Mathematics, a high school in Durham, won the $100,000 grand prize in the team category of the 2004-05 Siemens Westinghouse Competition in Math, Science, & Technology for a project studying the effect of DNA methylation on breast cancer. (Got that?) "Both of us have been interested in science ever since we were very young," says Guo. "Neither of us ever felt our gender was a detriment."

Their perspective is welcome amid the furor over a now- notorious speech by Harvard University President Lawrence H. Summers. At a Jan. 14 conference on the paucity of women in the sciences, he suggested there may be "innate differences" between male and female brains that make it harder for women to excel in math and science. He quickly backed down. And in fact most scientists say there's little evidence that men's brains, though different structurally than women's, are better or worse at specific intellectual endeavors. "Intelligence is always the result of an interplay between biology and environment," says Rex E. Jung, a University of New Mexico neurologist.

The furor over Summers' comments obscures a critical issue: Women must be encouraged to enter engineering and science if the U.S. is to remain economically competitive. This is particularly true given that science and math abilities in the U.S. are badly lagging other nations for both girls and boys. "We can't afford not to encourage women," says Janie M. Fouke, dean of the College of Engineering at Michigan State University. "Half the brightest minds in the country aren't at the table."

How do we get them there? We can start by eliminating some wrongheaded assumptions. Throughout their early education and college, girls and boys show the same interest and aptitude for science and math. Women took home 47.1% of all the science and engineering undergraduate degrees awarded in the U.S. in 2000. Most of these were concentrated in the life sciences and chemistry, and women earned only about one-fifth of undergraduate engineering degrees that year. Still, it's pretty clear that women are interested in the sciences.

The gender gap really emerges when it comes time to apply that education. Far more men than women go on to get masters and PhDs in the sciences, and the National Science Foundation says industry employed only 994,400 women in science and engineering in 2000, compared with 3.1 million men. Universities are even worse: Engineering school faculties typically run 10 to 1 male.

Here's how we can start to change those ratios:
MENTORING. Shirley Ann Jackson, president of Rensselaer Polytechnic Institute, says youngsters need personal encouragement. "They need the involvement of their teachers, their peer groups, of people who can serve as role models." Guo and Li, for example, say mentors were critical to their continued interest in science. "In the lab where we worked there were a lot of female scientists, and they were all very inspirational," says Li.

HIRING. To get such role models, colleges must actively recruit women. That might be easier if science careers were seen as more family-friendly. But it's more important to develop an atmosphere that's not hostile to women. Studies have found science papers are judged more harshly if it is obvious the author was a woman. It's tough to overcome these cultural biases, but strong leadership from women like Susan Hockfield, the president of Massachusetts Institute of Technology, is a start.

MAKE SCIENCE COOL. Truth is, boys are turning away from science as much as girls: The U.S. ranks below 13 other countries in the percentage of 24-year-olds with a math or science degree. "We have to change our culture to one that believes that it's really important to have a population that is well-educated in math and science," says Maria Klawe, dean of Princeton University's engineering school. If only that issue got as much attention as Summer's initial remarks.

By Catherine Arnst

http://www.bcs.org/BCS/Awards/Events/GrandChallenges/conferencereports

Grand Challenges in Computing

GC 04

Education

Andrew McGettrick, Roger Boyle,
Roland Ibbett, John Lloyd,
Gillian Lovegrove and Keith Mander

Organised by:

BCS The British Computer Society

CPHC Council of Professors and Heads of Computing

EPSRC Engineering and Physical Sciences Research Council

The IEE

northumbria UNIVERSITY

UK Computing Research Committee

University of Newcastle upon Tyne

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2 Challenge areas

2.1 Perception of computing

2.1.1 Situation

Public image and public understanding of any discipline will greatly influence parents, teachers, careers advisors and those who guide young people in their choice of more advanced study. Of course, they also influence young people themselves since they serve to make them curious about more advanced study and to consider a computing career.

The achievements of computing over its short lifetime are under-reported. Mistakes and disasters, rather than the achievements of the internet or the promise of nano-computing, appear in the news. There are many large and complex systems which function successfully and underpin many aspects of administration, the economy, societal matters and business; the internet is used daily by many people and its availability is taken for granted. The infectious excitement of computing often manifests itself in applications and remarkable advances associated with other disciplines. For example, space flight as we know it could not occur without major support from computers and computing. Likewise, the advances associated with the genome project and with certain theorems in mathematics fall into this category.

What kind of image of computing should one portray? It is certainly desirable to attract the best and responsible students into the discipline and to do so in significant numbers. The desirable image is one of an exciting even vibrant discipline where there are rapid and exciting developments, where these developments can help not only industry but also health care and the caring professions, as well as education. Computing offers great opportunities for innovation, challenge, and wealth creation.

For computing, the current public image tends to be less than ideal. The media will often focus on disasters of various kinds, on stories about new viruses and the damage these can do, about security breaches, about intrusions from ugly and unwanted spam, and generally on incidents that are criminal or border on the irresponsible. Those who use computers are often frustrated by curious software bugs, by software that will not perform as required, by systems that are too complex to understand and too difficult to use. Of course, much of this relates to the nature of software itself; nevertheless, the image portrayed is not kind.

2.1.2 Challenge

Given the situation described above, the computing challenge for this area is as follows:

> Promote an improved and ultimately very positive public image of computing, ensuring that the public gains respect for the field and the professionals who practise within it.

2.1.3 Motivation

As advances unfold and future progress towards ubiquitous computing emerges, the unsavoury matters (associated with spam, security violations etc.) could have the potential to strangle developments in computing. In all of this there are medical analogies, reflected in the use of terms such as ‘virus’ and ‘epidemic’, where the solutions can also be couched in medical terminology.

To address these concerns a number of initiatives have been undertaken. For example, in security and related matters, grand research challenges from Computer Research Associates (CRA, 2003 a and b) include (but are not restricted to) the elimination of epidemic-style attacks (from viruses, worms, email spam etc) within 10 years and the development of tools and principles that allow construction of large-scale systems for important societal applications, such as medical records systems, that are trustworthy despite being attractive targets. Another is to build distributed computer systems, which in the event of some major disaster can be relied on to continue to function effectively and efficiently (Jones *et al.*, 2003).

Looking at the scene from a different perspective, IBM has initiated the concept of autonomic computing (Ganek and Corbi, 2003). The aims of autonomic computing are to produce systems that are

> intelligent in the sense that they understand themselves and are able to manage themselves so that they adapt to both predictable as well as

unpredictable situations or occurrences, even tune themselves and recover from failure.

The intended result is that there is a decrease in the need for tedious maintenance and a consequent reduction in the frustration of users. The resulting systems can be described as self-managing, self-healing, self-protecting, and generally are able to self-diagnose, to predict and to adapt to dynamically changing environments and situations. There are, of course, implications here for the safety and for the security of such systems.

In the area of usability concerns, one of the grand challenges from Jones *et al.* (2003) concerns building systems in which users, software agents, and robots can work in harmony to enhance the productivity and capability of an individual. This is particularly relevant when dealing with such matters as natural language translation in real time in a variety of user contexts and situations, compensating for disability, and so on.

These are only examples of the possibilities and they hint at a considerable cross-fertilization of ideas. For instance, maturity models have their origins in studies of the software development process. In the case of autonomic computing, for example, a similar kind of maturity model can be associated with the development of such systems: thus, there is a basic level, a managed level, a predictive level, an adaptive level and a fully autonomic level. There are mechanisms and steps that we can define and describe to aid transition from one level to the next. This idea of levels is significant and has wider applicability.

Another important aspect of the required image of computing is that it should be outward looking and inclusive. In part this is to reflect a discipline that remains in a rapid state of evolution and consequently there is merit in seeking ideas and concepts from other disciplines and elsewhere. These can aid and encourage (perhaps through abstraction, absorption and/or cross-fertilization) the future development of computing. Therefore, in creating an image of computing, it is important to project a discipline with a strong central body of knowledge with sound underpinning etc, but for which it is important to illuminate the beneficial relationships with other disciplines.

What are the factors that influence the public image? Certainly, there are the matters reported in the press and in the media generally; mechanisms exist for influencing these and they should be used. In these endeavours it is important to draw attention to the ever-increasing range of the important applications and positive images involving computers coupled with the benefits these bring to individuals, to society, to industry, to commerce, and so on. Other influences include such matters as the reliability of many computer systems, the trust that the public can place in them, and the ease of use of such systems. The challenge is to place positive images before the public to balance and even negate the reports of disasters and failures.

The very concept of a grand challenge itself merits attention from another perspective. We can use the existence of these challenges to fire the imagination, to tell the public (as well as others, e.g. those in positions of influence) about those matters that the computing community sees as being important, and why. Apart from other considerations, this serves to reinforce the view that there remains much to do in computing and the products of this endeavour have the potential to bring huge benefit and advantage.

2.1.4 Sub-challenges

Within this grand challenge it is possible to identify a number of interim challenges or sub-challenges that can inform and testify to progress towards meeting the main challenge:

- Promote a positive image of computing both by expounding the real achievements of computing and by articulating the aspirations and ambitions of research-based grand challenges that highlight a vision for development and innovation and create anticipation and excitement.
- Illuminate the links with other disciplines highlighting the advantages that such links provide and pointing to the future benefits of productive alliances with them; use these also, where appropriate, both to clarify the nature and extent of computing as a discipline and to further the development of computing as that discipline.
- Develop metrics that provide a barometer of the health of computing as a discipline and then use these metrics to measure and monitor the progress towards improvement and to guide future developments.
- Participate in research-based challenges whose purpose is to promote an improved image of computing.

2.1.5 Measures of success

We wish to associate various metrics with this challenge as noted in the sub-challenges above.

2.7 Pre-university issues

2.7.1 Situation

Universities recruit students from high schools and, in UK terminology, colleges of further education. They then aim to convert them into graduates. Students come from disparate backgrounds and offer a wide range of entry qualifications. As official governmental policies tend to widen participation, this trend will continue and the accepted benchmarks regarding entry may seem increasingly less applicable.

Computing is in an odd position. Currently, no universally accepted pre-university computing qualification for entry exists; many programmes will require some level of mathematics, for instance, but few, if any, require a prior qualification in computing. A steady but clear growth in demand for university computing places has existed for many years; this growth peaked during the 'dot com bubble' and has now fallen back to a point nearly in line with the long-term trend. In the short to medium term, the trend is likely to continue.

The vocational nature of important aspects of the subject makes it a popular choice for many students, especially as universities demand explicit sums of money for their wares. The motivation for this choice is not always primarily academic. There is often a very poor understanding by new students of what the subject is, and what they will study (often related to the preceding point). In computing, the issue is exacerbated by the wide exposure of the pre-university community to computers in many routine ways, often misleading students about the nature of the subject.

The subject appears in some guise in most schools. Professionally, however, computing qualifications are widespread, and information technology (or ICT as it is sometimes called) appears as a qualification and manifests as a 'key skill'. Abundant anecdotal evidence and statistics reveal that the number of qualified computing graduates on high school staffs is very low. Teachers with a first speciality in another subject usually purvey computing. There is no suggestion that computing is inadequately or poorly taught (indeed, evidence to the contrary is available), but there is typically an absence of the enthusiasm and knowledge that comes with the depth of a higher education qualification in computing itself.

There is significant influence on computing in higher education from the 'demand' side, namely students and employers. Part of this influence is on the choice patterns of entrants, but there is also an effect on the curriculum, both implicitly from university staff knowing (or thinking they know) the requirements of employers, and explicitly via a number of organizations and government agencies enumerating 'what they want' (e.g. Career Space, 2004).

2.7.2 Challenge

Given the situation described above, the computing challenge for this area is as follows:

> Rationalize the situation at the pre-university level and direct it towards the promotion of computing to would-be students of computing. Create for students a smooth transition from school to university by enthusing and informing potential students and by creating a positive influence affecting pre-university computing.

2.7.3 Motivation

A number of surveys have occurred and these highlight significant issues. On being asked what they are expecting to study, entrants to university computing programmes usually are unaware of what they are going to study in a way that entrants to other disciplines are not. This can lead to disappointment and dissatisfaction. Surveys of dropouts reveal this as a major cause of high attrition.

Surveys of universities report that a primary source of information to entrants is teachers: computing or careers teachers. Hence, it is a contributory factor that those guiding students are often unaware of what higher education study of computing might involve. This problem extends to a lack of awareness of what careers in computing might be, or careers in industry and commerce that lead on from computing degrees. It also has to be recognized that the problems are often exacerbated by a lack of awareness among university staff of what is taking place within schools and colleges and their curricula. Generally the gender imbalance of university intake to computing programmes in certain countries is well known, as is the unevenness across many other population groups.

It seems *probable* that in ten years, the penetration of computers into society, coupled with government enthusiasm for ICT in all its guises, will lead to the emergence of a qualification among entrants that computing understands and respects. If this is the case, it implies a threshold point at which it becomes true, and has consequences for equipment in schools (or at home) to support the technologies used. This is not to suggest or to encourage the establishment of some advanced computing qualification as a prerequisite. Rather, the intention would be to identify an agreed suitable foundation that would be of value to those who did not wish to specialize in computing in higher education as much as to those that do.

Issues of resource, in any event, could easily have a backlash on any desired strategy. These issues are more difficult in the UK than in the USA[2], for instance, because of the traditional inflexibility of certain UK degree structures. The intention is not to decrease the amount of material in computing degrees, but to provide more space within them for breadth and depth.

There is no doubt that computing is currently unusual in having relatively few of its graduates active in secondary and tertiary education; this is at variance with a number of other disciplines (such as psychology, sociology etc.) which do not stipulate discipline prerequisites, but whose graduates frequently do choose to go into teaching. This means that pre-university computing students rarely benefit from the disciplinary input that comes from teachers and lecturers who are able to take them beyond the formal curriculum.

There is no doubt that programming is a major issue in the teaching of computing, often dominating the student experience in higher education (discussed in section 2.4). There is evidence beyond the merely anecdotal that programming (as understood within universities) is rarely encountered in schools and colleges of further education. In a five to ten year period, this state of affairs is likely to evolve. For example, already more than 40 per cent of homes in the UK have domestic computers – a proportion that will grow – and it seems plausible that the incidence of the desire to learn programming among the pre-university community will grow. Should this happen it would be desirable to influence its nature, while not intending to dictate *what* language is taught[3]. Circumstances would improve enormously if there was some basic agreement on that issue.

Fundamentally, one should view an education in computing as an extremely valuable commodity for the technological society of today. Apart from the knowledge and understanding, as well as the associated confidence and marketability, an education in computing imparts a range of valuable skills. These include: the ability to structure and organize information; to take disciplined approaches to problems and to complex situations; to recognize the power of life cycle models, of the concept of process and the associated improvement and enhancement possibilities; to recognize the power of abstraction including the different levels of such abstraction; to appreciate the elements of good design in all its forms; to recognize the need to carry out risk assessment in sensitive situations; to value and strive for innovation; to recognize the professional, legal and ethical issues associated with a profession.

2.7.4 Sub-challenges

Within this grand challenge it is possible to identify a number of interim challenges or sub-challenges that can inform and testify to progress towards meeting the main challenge.

- Engender in potential students a sensible understanding of the range of possibilities of advanced study of computing and, where appropriate, to ensure that they possess the skills needed to undertake successful study of (some aspect of) computing in higher education.
- Communicate to teachers and careers advisors what university computing and computing careers are, and what computing degrees might lead to.
- Understand/verify reasons for the low percentage of some population sectors (notably women) among applicants, and the reasons for the disproportionate appeal of the discipline to some other groups.
- Ensure that those entering higher education to study computing form a representative cross section of society in terms of gender, ethnic origin etc, and yet also compensate properly for diversity in intake expectation, ability, maturity and experience.
- Establish resource (time) for teachers and university staff to develop a mutual understanding of one another's problems. Encourage university staff to appreciate that students' expectations are coloured by their life-experience and not by the history of computing. Understand the prerequisites required to support successful study of the different flavours of computing in higher education bearing in mind that introducing new prerequisites conflicts with the aims of widening participation.
- Have pre-university delivery of high quality computing courses informed directly by and consistently performed by appropriate active academic computing graduates.
- Develop a clear view of the issue of programming at pre-university level and have a positive influence on the development of appropriate curricula.

2. We note that in the USA the involvement of the ACM with school activity is considerable: note in particular the Java Engagement for Teacher Training project (see http://satchmo.cs.columbia.edu/jett/).
3. Language wars within higher education are, in any event, rife.

2.7.5 Measures of success

We can associate various metrics with the challenge and sub-challenges as follows. In five to ten years, it might be reasonable to expect a prior computing qualification. This could include explicitly programming to some level and some understanding of 'algorithm'. So metrics might include:

- The incidence of the home-ownership of properly and easily programmable computers.
- The incidence of appropriately qualified computing graduates on the staff of high schools and colleges.
- The establishment and widespread acceptance of proper mechanisms to compensate for entrants with demonstrable prior qualification.
- Demonstrable understanding by university staff of school/college activity and syllabuses.
- The incidence of higher-education-based continuing professional development for computing teachers in schools/colleges.
- Average standards of those entering to study computing are no worse (and ideally better) than those entering to study related disciplines.

Ultimately success in improving such metrics should lead to:

- Dramatic improvements in the proportion of women and other under-represented sectors in intake.
- Improvements in retention rates so that, for instance, at most 10 per cent of university entrants drop out at the end of first year.