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Demystifying the Academic Research Enterprise

Becoming a Successful Scholar in a Complex and Competitive Environment

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14

A Glass Half Empty or Half Full: Challenges and Opportunities for the US Academic Research Enterprise

Chapter Overview and Learning Objectives

From its world-class research institutions to its production of world-renowned inventions, the US is a global leader in research and innovation. Yet, certain challenges must be addressed in order to maintain this position in an increasingly globally competitive environment—an environment in which other nations are investing heavily in R&D and related education, and in which some governments are interfering with and actively undermining our research and innovation enterprise.

This chapter describes past trends, possible future directions, and emerging opportunities in the US research enterprise and presents a variety of comparisons between the US and other nations. After reading this chapter, you should

- Be able to compare and contrast the state of research investment, productivity, and other related measures of the US and the rest of the world;
- Understand the importance of a strong education system for the future of research and technology development;
- Understand the trends of participation of various demographic groups in STEM education and careers;
- Understand the importance of diversity, equity, and inclusion in ensuring American leadership in science and technology; and
- Identify various challenges faced by the US academic research enterprise and actions that can be taken to meet them.

14.1 Comparisons between the US and Other Nations

In this final chapter, it is appropriate to step back and consider the challenges, and also the opportunities, within the US academic research enterprise. Let

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us begin by looking at the current situation and underpin our assessment with hard data.

The US has long been a world leader in research and innovation, especially fundamental research conducted at academic institutions. Of the top ten universities in the world, five or more are located in the US according to multiple assessments. Of the top twenty, roughly half are located in the US.

The US has produced three times as many Nobel laureates as its nearest competitor, and the number of innovations that have sprung from research conducted in the US literally boggles the mind. The transistor. The digital computer. The Internet. The global positioning system (GPS). Chemotherapy. The LASER. The LED. Computer-based weather forecast models. And the list goes on and on. The US boasts a massive number of private foundations that fund research and creative activity, in addition to twenty-six federal agencies and untold private companies. In fact, the US now expends well over half a trillion dollars each year on research and development.

Let us put this in context with the rest of the world, particularly with regard to trends across a number of key research and related metrics. The gold standard source of information regarding such metrics is NSB's biennial (published in even years) Science and Engineering Indicators (SEI), which is a comprehensive set of data on the state of science and engineering research and education in the world. Now fully available online, SEI contains only data, trends, and analyses, not predictions, and by statute it offers no policy recommendations. Given the dependence of SEI upon surveys and other data that require considerable time to collect and analyze, many of the measures are lagging indicators and are two or three years old when published. However, most such measures do not change appreciably during that time.

Figure 14.1 shows gross domestic R&D expenditures in billions of purchasing power parity (PPP[1]) dollars, by country, over the period from 1990 to 2017. Although the US and the EU are growing at roughly the same rate of 4 to 5 percent per year after 2010, the most striking feature is the rapid growth of expenditures by China—at approximately three times that of the US and the EU. As a result, the US share of global R&D dropped from 37 percent in 2000 to 25 percent in 2017. Although increases in the research output of other nations is to be celebrated given that research is a global enterprise, it is important for the US to continue increasing its investments as well.

Another way to portray government investment is via R&D expenditures relative to a country's GDP.[2] This ratio is important because it shows the fraction invested in R&D of a nation's total value of goods and services produced. Shown in figure 14.2, the R&D-to-GDP ratio of the US has been roughly constant since 2008, consistent with that of most other nations. The exceptions

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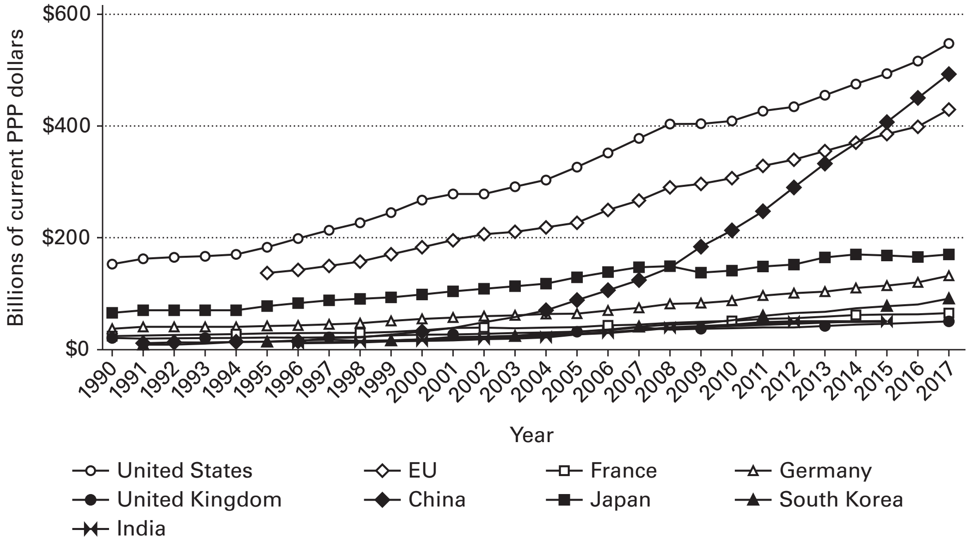

Figure 14.1
Gross domestic expenditures on research and development, in purchasing power parity dollars, by selected region, country, or economy, 1990–2017. *Source*: National Science Board (2020d).

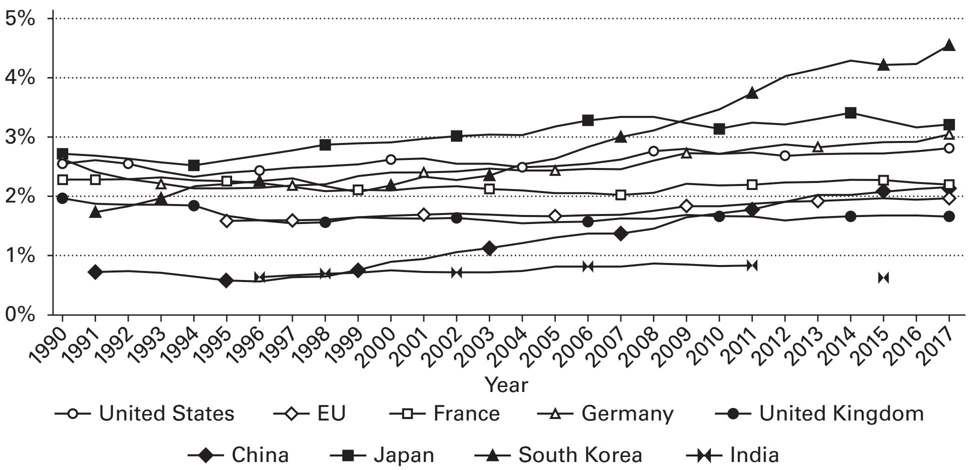

Figure 14.2
Gross domestic expenditures on R&D as a share of gross domestic product, by the US, the EU, and selected other countries, 1990–2017. *Source*: National Science Board (2020e).

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are China and South Korea, both of which exhibit steady increases for two decades or more, with South Korea increasing sharply.

Turning to measures other than dollars, scholarly publications represent the end product of research (especially fundamental research) and are a valuable measure of productivity. Figure 14.3 shows science and engineering articles produced, by global share of selected region, from 1996 through 2018. Note the US share has steadily declined and now is well below 20 percent, while China surpassed the US a few years ago, with other developing countries now increasing as well. Again, the rise in publications from other nations is a net positive, though it is important the US remain strong. Total patents granted by national office in 2021 (https://wipo.int; not shown) indicate China with a more than 2 to 1 lead over the US, though the value of many of China's patents remains questionable (He 2021).

The production of college degrees is an extremely important indicator of workforce capability and capacity and thus future research and development. Figures 14.4 and 14.5 capture this information for baccalaureate (first) as well as doctoral degrees in science and engineering fields. In the case of baccalaureate degrees, the US and the EU have grown at roughly the same rate, though both exhibit a flattening during the past few years. China began exhibiting rapid growth starting in 2002 and the trend continues unchanged, though as

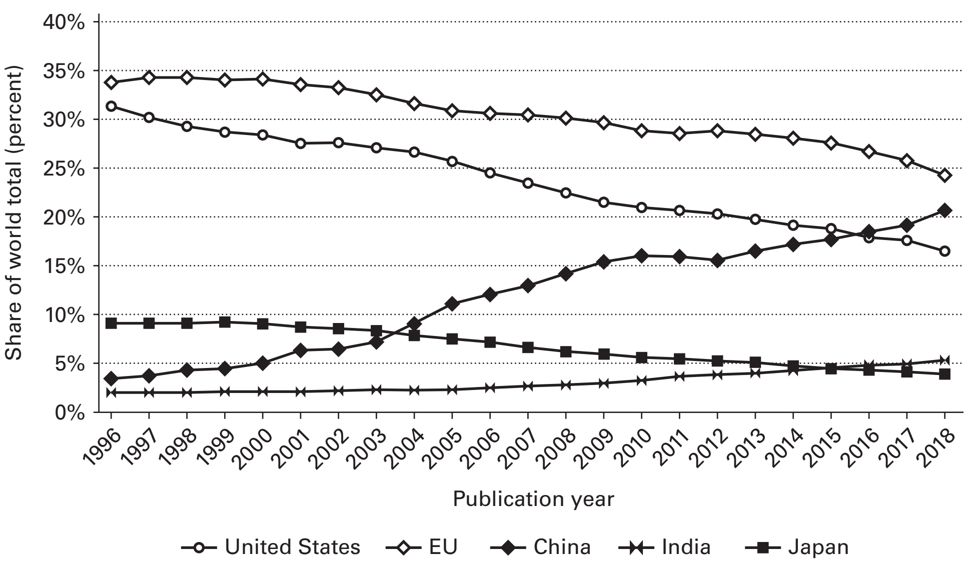

Figure 14.3
Science and engineering articles, by global share of selected region, country, or economy, 1996–2018. *Source*: National Science Board (2020c).

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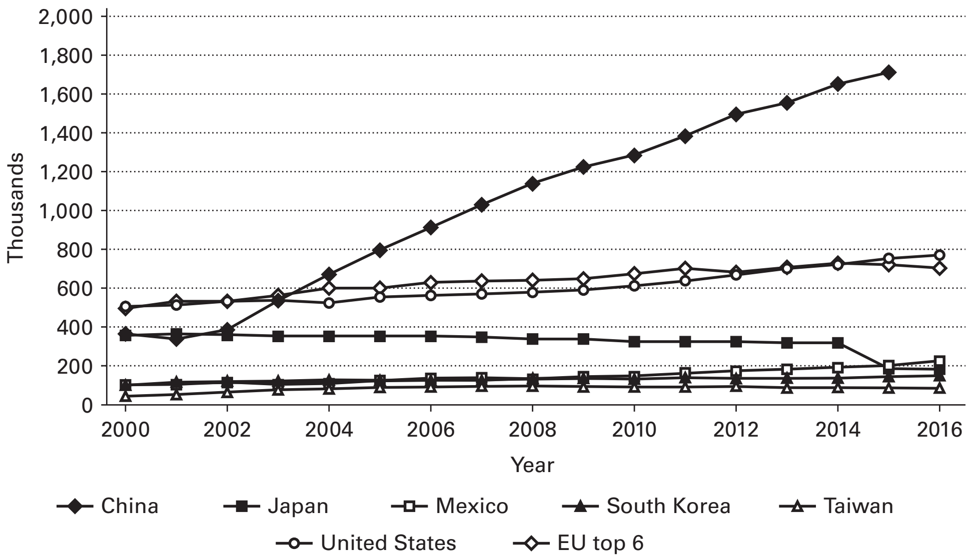

Figure 14.4
First university degrees in science and engineering, by selected region, country, or economy, 2000–2016. The EU top six includes France, Germany, Italy, Poland, Spain, and the United Kingdom. *Source*: National Science Board (2020h).

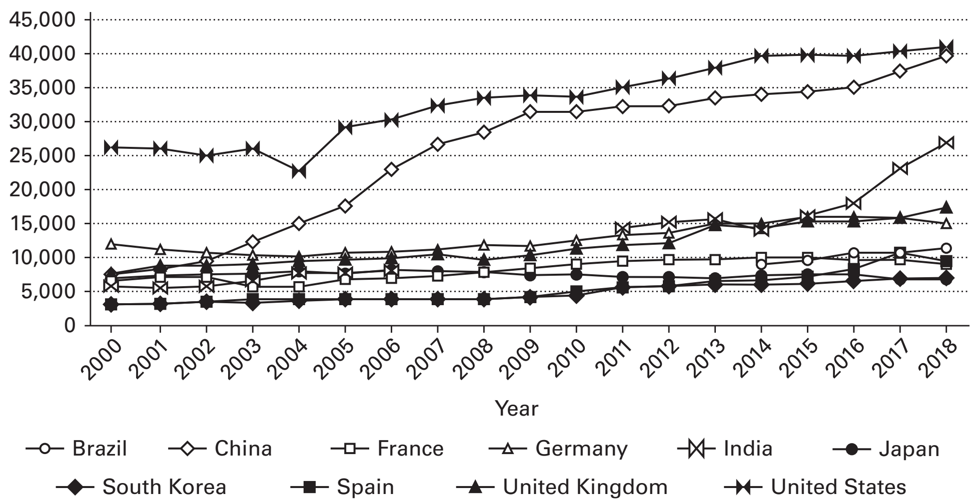

Figure 14.5
Doctoral degrees in science and engineering, by selected region, country, or economy, 2000–2018. *Source*: National Science Board (2022a).

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noted previously, these data lag by five years. In the case of doctoral degrees produced, the US and the EU grew at roughly the same rate for several years, though both exhibit a flattening during the past few years. China exhibited rapid, sustained growth from 2002 until 2010, followed by a flattening as well starting in 2013, with a notable uptick beginning in 2016.

An important consideration in the context of STEM fields is not only the production of STEM degree recipients for the critically important STEM jobs upon which our research and innovation economy depends, but also the creation of a STEM-enabled workforce. That is, individuals who have degrees in non-STEM fields, such as the humanities, but who possess some STEM capabilities via taking STEM courses or through practical experience. As an example of the importance of a STEM-enabled workforce, approximately 25 percent of information technology workers in the US do not in fact have a STEM degree.

14.2 US Education Statistics

I am sure you are aware that demographics in the US are changing dramatically. According to the US Census Bureau, the US increasingly is pluralistic, meaning no race or ethnic group will have a share of more than half the total population. In fact, the Census Bureau projects that 32 percent of Americans will be a race other than White by 2060. As a result, in order for the research enterprise to remain robust, enhancing the participation of traditionally underrepresented, underserved, or marginalized individuals is critically important. This is true in terms of college accessibility as well as subsequent employment. Progress has been slow, as shown in figure 14.6, which depicts the receipt of science and engineering master's degrees by race, ethnicity, and citizenship. The situation is a bit better for baccalaureate degrees (not shown), with Hispanics and Latinos seeing the greatest progress.

Figure 14.7 shows that the percentage of STEM bachelor's degrees awarded to Asian students (33 percent) was almost double the percentage awarded to students overall from 2015 to 2016. In contrast, the percentages of STEM baccalaureate degrees awarded to Black, American Indian/Alaska Native, Hispanic, and Pacific Islander were lower than the percentage awarded to students overall. Because of the disproportionate number of women and underrepresented minorities pursuing STEM careers, particularly within academia, agencies such as the National Science Foundation have begun initiatives such as the ADVANCE (Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers) program, which is designed to increase participation and advance diversity in academic STEM careers.

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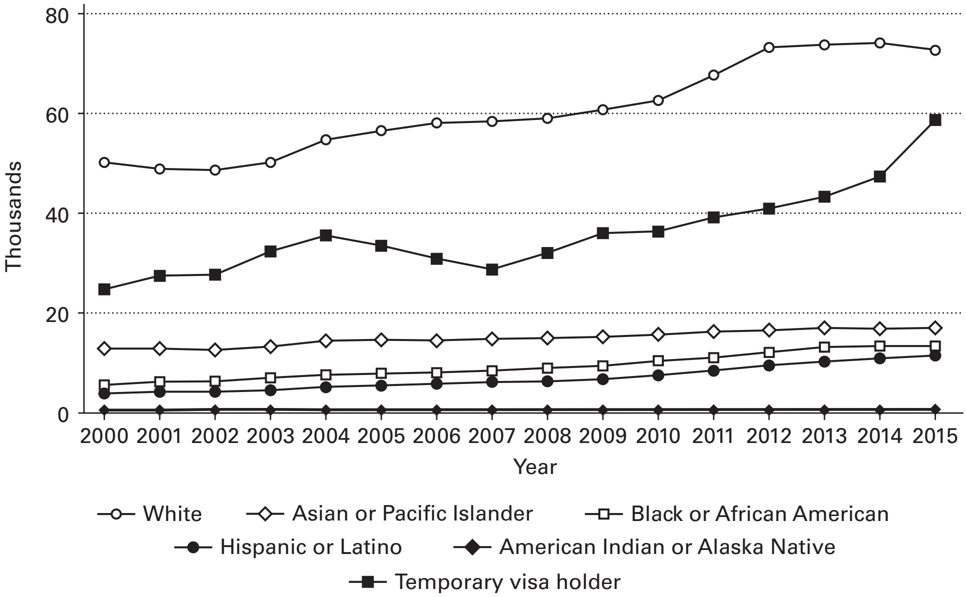

Figure 14.6
Science and engineering master's degrees, by race, ethnicity, and citizenship, 2000–2015. *Source*: National Science Board (2018c).

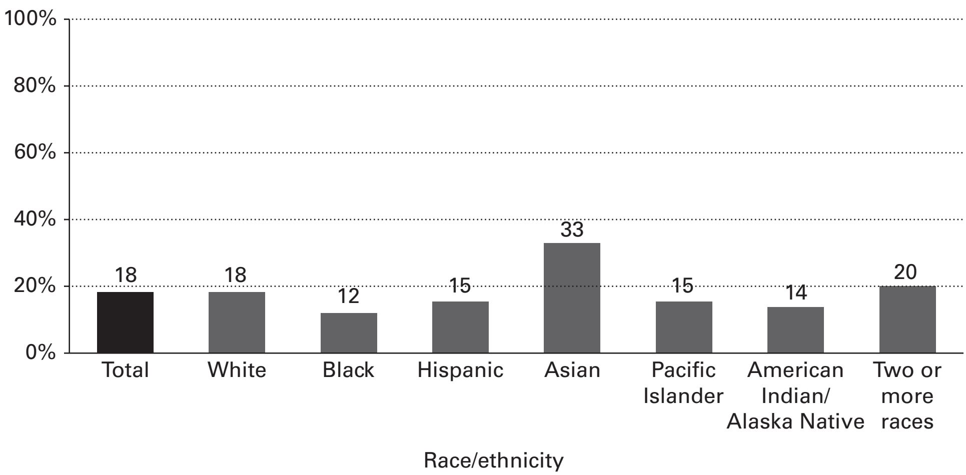

Figure 14.7
STEM bachelor's degrees as a percentage of total bachelor's degrees conferred by postsecondary institutions, by race/ethnicity, for the academic year 2015–2016. *Source*: National Center for Education Statistics (2019).

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Looking a bit more closely at measures for women, figure 14.8 shows women's share of science and engineering degrees, by degree level and field, in 2017. In all fields combined, women dominate at all levels, driven mostly by dominance in psychology and the biological sciences and at the doctoral level in the social sciences. Clearly, more progress is needed for women in computer science and engineering.

Figure 14.9 shows trends for women bachelor's degrees from 2000 through 2015. Since 1982, women have outnumbered men in undergraduate education. And, since the late 1990s, women have earned about 57 percent of all bachelor's degrees and half of all science and engineering bachelor's degrees. The curves since 2000 for women are basically flat, except for computer science, which exhibited a drop of 10 percent during this time.

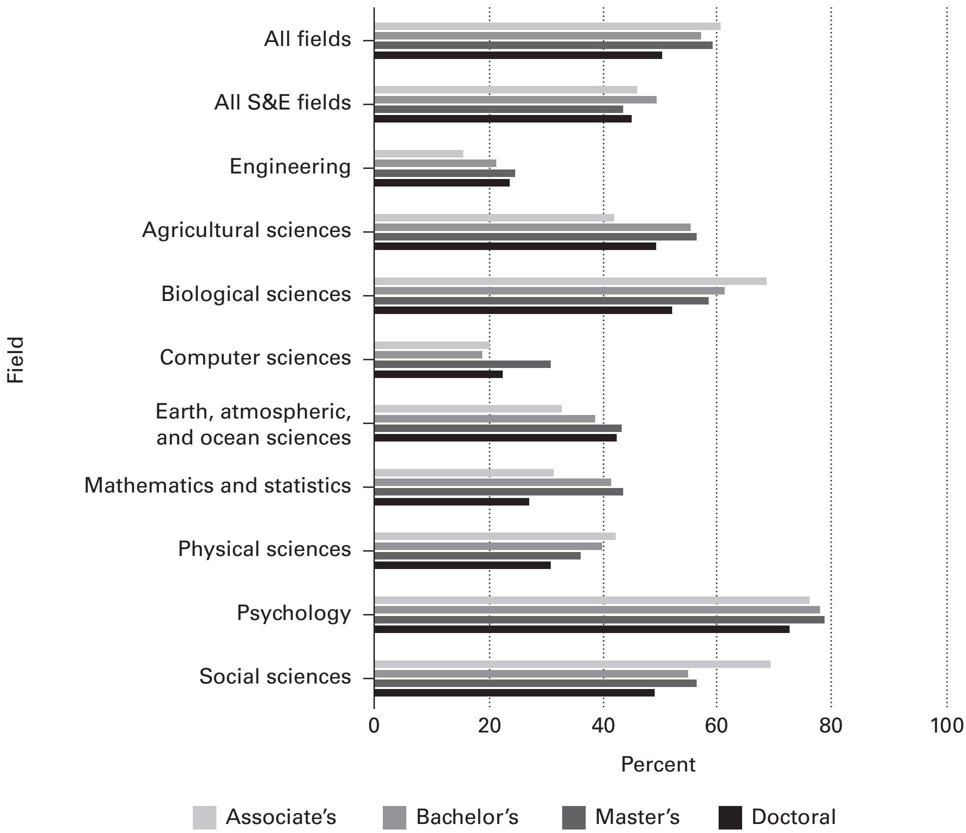

Figure 14.8
Science and engineering degrees awarded to women, by degree level and field, 2017. *Source*: National Science Board (2019a).

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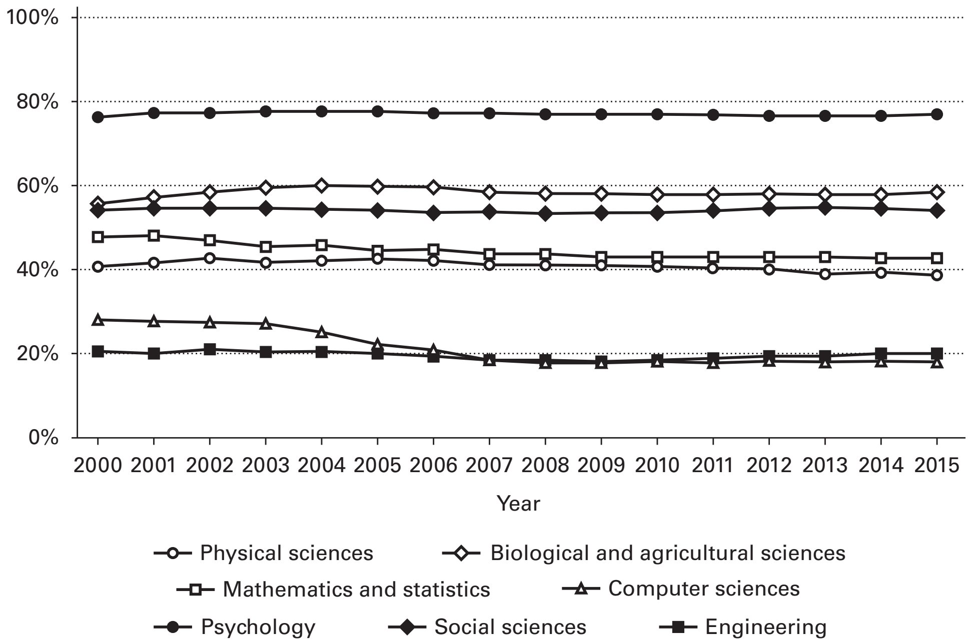

Figure 14.9
Women's share of science and engineering bachelor's degrees, by field, from 2000 through 2015. *Source*: National Science Board (2018b).

Of course, college readiness and success depend upon adequate preparation in grades K–12, and the NSB science and engineering data contain a wide array of measures on K–12 performance in the US compared to other countries. Space does not allow for a comprehensive treatment of this important topic, so here are a few key points from the 2018 edition of SEI.:

- Less than half of fourth, eighth, and twelfth grade students achieved a level of proficiency, defined as "solid academic performance" or higher, on standardized mathematics and science assessments in 2015.
- Performance disparities in mathematics and science were evident in 2015 among different demographic groups at all grade levels, beginning as early as kindergarten and persisting through subsequent school years.
- For the latest data available, US average mathematics assessment scores were well below the average scores of the top-performing education systems in the world. And the US performs better internationally in science literacy than it does in mathematics literacy.

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14.3 Challenges Facing the US Academic Research Enterprise

Several challenges face the US academic research enterprise, and here I mention those which I believe to be most important. The first concerns the level and, equally importantly, the predictability of funding available for research from federal agencies. Establishing and growing a research program requires some degree of certainty that adequate funding will be available. Just as the stock market hates uncertainty, so do researchers when it comes to funding. This is particularly true for federal funding directed toward fundamental or curiosity-driven research, and several recent reports have called for sustained, significant increases.

Among the most notable documents is American Academy of Arts and Sciences (2014), which proposes increases in fundamental research support that would put the US back on a trajectory similar to that which existed from the mid-1970s through the early 1990s (figure 14.10). During that period, inflation-adjusted annual growth for federal investment in fundamental research was approximately 4.4 percent. Since then, investments have fluctuated, never

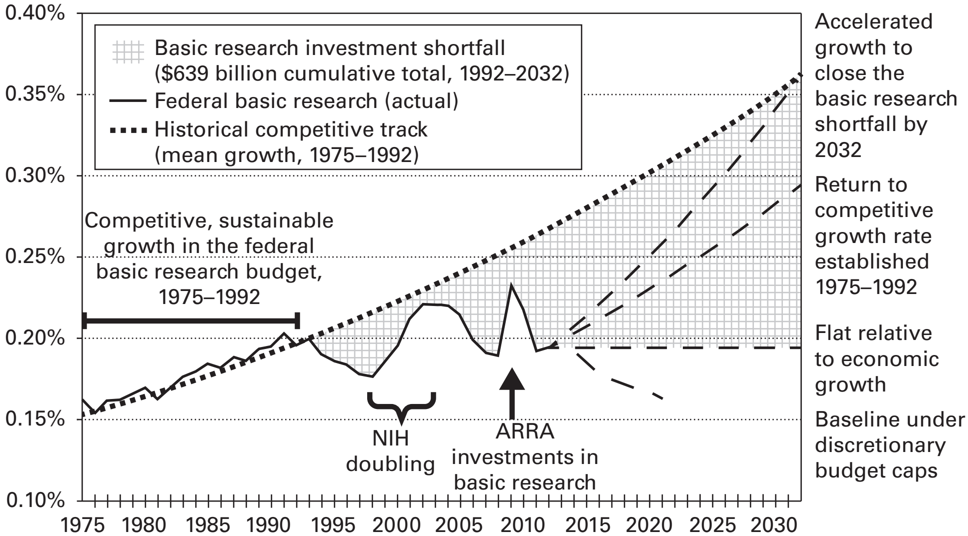

Figure 14.10
US federal basic (fundamental) research investment, in current dollars, as a share of gross domestic product. The dotted line is a least-squares fit of federal obligations for basic research during the period from 1975 to 1992 and is projected out to 2032. The hatched region shows the difference between this curve and a budget that is flat relative to economic growth. The shallow dashed line shows the rate of investment needed to equal the long-term projection by 2032, and the steep dashed line shows the rate of investment needed to close the funding gap by 2032. *Source*: American Academy of Arts and Sciences (2014).

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recovering in a sustained manner to previous levels. The report provides recommendations to address this and other challenges.

Second, as noted in chapter 10, the number of research compliance rules and regulations has grown dramatically during the past thirty years and in many cases is hampering research without meaningfully driving behavior in desired directions. This is an especially acute problem for MSIs, ERIs, and institutions that focus primarily on instruction but seek to become more active in research. As Congress increases funding for research at such institutions, it must recognize that such increases require concomitant scaling of administrative frameworks (section 12.3), and that additional research activity can fundamentally change institutional culture. Although good progress is being made to address these issues, including reducing researcher administrative workload (section 10.6), more needs to be done.

Third, especially in times of tight research budgets, the degree of patience exhibited by Congress and others regarding practical outcomes from research investments tends to diminish. Yet, as noted in this book, the time taken for fundamental research results to manifest themselves in ways seen as practical can be quite long, even a few decades. It is important for the US to have a balanced portfolio among all funding sources such that the entire research ecosystem, which as we saw in chapter 3 is highly intertwined, can be successful.

Fourth, as noted previously, increasing the diversity of the scholarly enterprise, particularly in STEM fields, is critically important to the future of research and creative activity. Here, I interpret diversity in the broadest possible manner to include attributes of race, ethnicity, gender, sexual orientation, geography, military service, age, religion, political affiliation, viewpoints, and country of origin. To be successful and serve as a beacon of values through practice, not merely words, the American research enterprise not only must welcome all potential participants, but also take steps to ensure that everyone who wishes to become involved has the opportunity to do so.

Fifth, we must never forsake the arts, fine arts, and humanities in seeking to cure cancer or build the next transformative invention. Our humanity, in its many dimensions of richness and expression, is as important to our future as the next technological discovery. Scholarly pursuits in all areas are essential to our future and must continue.

Finally, this book has addressed the academic research enterprise. Consequently, its future depends upon that of the academy itself; that is, on the health and well-being of our system of postsecondary education. Colleges and universities are in the midst of significant challenges for a number of reasons. They include the value of a college degree relative to its cost, associated with which has been a loss of the fundamental notion of higher education as a public good;

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the need to be more inclusive while maintaining high standards; a diminution of universities as the place where divergent viewpoints are welcome and thoughtful debate occurs without fear of retribution; uncertain federal support for tuition aid; continued increases in regulation; and online education, which is of great value for many reasons but could fundamentally alter the financial structure upon which institutions have always operated.

It is well documented, as shown in figure 3.3, that funding for public research universities dropped significantly following the Great Recession in 2008/2009. Although the trend is now reversing, appropriated funding for public colleges and universities remains well below that of a decade ago in real spending power—and thus tuition costs have risen as a means to offset a large part of the difference.

14.4 Looking Ahead

Despite many challenges, some of which are significant and have no simple solutions, I remain very optimistic about the future of the US research enterprise, as described in the afterword. And I know most of my colleagues share that view. Although we cannot ignore and are not ignoring those challenges, our nation is better positioned than ever before to continue discovering, innovating, educating, and leading the world as a beacon of progress and prosperity. Opportunity abounds for you, as a researcher, to participate. The tools available to you, the vast repositories of knowledge at your fingertips, and the need for creative minds to tackle society's most stimulating and compelling problems have never been greater. Seize the moment. Unleash your curiosity and desire to discover. The only limitation you face is that which you place upon yourself. As Michelangelo is said to have brilliantly stated, "The greatest danger for most of us is not that our aim is too high and we miss it, but that our aim is too low and we reach it."

Assess Your Comprehension

1. List a few measures demonstrating American leadership in research and innovation globally.
2. How many more Nobel laureates has the US produced than its nearest competitor?
3. What countries are today investing the most in research and development and how have these investments changed over the past twenty years?
4. How has the share of scholarly publications by the US changed over the past twenty years and what changes have occurred in other countries by comparison?

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5. How does the US compare to other nations with regard to patents issued?
6. How does the US compare to other countries in the production of baccalaureate degrees?
7. What progress is being achieved by the US in diversifying degrees in science, technology, engineering, and mathematics (STEM) fields?
8. How does progress in diversifying STEM degrees compare with trends in population demographics?
9. How do women fare relative to men in science and engineering degrees awarded?
10. What key challenges face America's scholarly enterprise over the next several years to decades?
11. What reasons exist to be optimistic about the future of America's scholarly enterprise?

Exercises to Deepen Your Understanding

Exercise 1: The pathway toward a successful future research enterprise depends upon having a sustainable pipeline of students engaged in research. In particular, our nation's research and innovation enterprise needs greater numbers of individuals seeking degrees and expertise in science, technology, engineering, and mathematics (STEM) fields, particularly women and those from underrepresented minority groups. For this exercise, design the framework of a program that would stimulate interest, and provide for participation by K–12 students in research and creative activity, so as to ensure an adequate flow of talent into career techs, colleges, and universities. In framing your program, consider the following:

- What specific goals do you seek to achieve?
- Who is your target audience?
- What program structure will you use?
- What resources will you need?
- How is this program different from existing programs?
- How will this program improve participation by individuals from underrepresented groups? How can you most effectively ensure involvement of these groups?

Exercise 2: A recent report (National Science Board 2019b) highlighted the critical importance of a skilled technical workforce (STW) in America's science and engineering research enterprise. For this exercise, read the report

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and develop a strategy for ensuring an adequate supply of talent within, and an appropriate balance between, an STW that supports research and creative activity compared to education pathways for those within the enterprise who have more advanced degrees and are performing the research. How would you incentivize those wishing to enter the STW? What education and training options are available to them? Consider issues such as affordability, accessibility, lifelong earnings, and reskilling opportunities for those already in certain trades (e.g., welders, electricians, heating/ventilation/air conditioning experts, machinists).

Exercise 3: This chapter pointed to a number of trends in international science, engineering, and technology research in which other nations are gaining ground relative to the US. What actions can the US take, both in terms of funding and policy, to ensure it remains a global leader in research while also serving as a collaborative partner? Speak specifically to issues that might be inhibiting multinational collaboration, such as differences in intellectual property ownership policies among nations, concerns about the theft or misappropriation of research results (chapter 10) by some foreign governments, immigration policies, and so on. You may wish to consider examining the European Union's (EU) Horizon Europe (European Commission n.d.) program and the challenges it poses for US engagement in research.

Exercise 4: Holding a degree (or degrees) in higher education has been documented to result in greater lifelong earnings and earning potential. Additionally, higher education has long been viewed as a public good, bringing benefits to society broadly in addition to those accruing to degree holders. Yet, the focus today is much more on a college degree as a pathway to a job or career, as evidenced by decreased public investment and the growing cost of higher education. For this exercise, describe how you would go about reframing the value proposition of higher education, including research, as a public good in addition to a private (individual) good. Which stakeholders are most critical for you to reach (e.g., students, parents, faculty, university administrators, Congress, the White House, private industry), and how would you most effectively make your case given the broad array of views held by them regarding higher education?

Exercise 5: The success of America's research enterprise—across all disciplines and sectors in which research and creative activity take place—is due in no small part to individuals from other nations who come to the US., receive a college education including advanced degrees, and remain here as productive citizens. Yet today, other nations are investing heavily in

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research and education, thereby providing other high quality and less expensive options for their citizens even though America remains the destination of choice. How can the US ensure it continues to be viewed as an attractive destination for foreign nationals? Discuss this issue with some of your peers from other countries who are either studying or conducting research in the US and obtain their opinions and points of view. Compare their input with current policies regarding foreign nationals in education and research (e.g., H-1B visa program) and suggest changes to improve the system.

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